MANAGEMENT STUDIES RELATING TO MECHANIZATION OF TARO (*COLOCASIA ESCULENTA* (L) SCHOTT) CULTURE

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TO: DR. W.G. SANFORD

I CANNOT EXPRESS HOW
MUCH I APPRECIATE YOUR HELP,
ENCOURAGEMENT ETC. THE FACT
THAT YOU WERE MORE THAN AN ACADEMIC
ADVISER MADE A LOT OF DIFFERENCE TO MY
PERFORMANCE AS A STUDENT.

MAHALO

ABSTRACT

There has been a gradual decline in the production of taro, Colocasia esculenta, in Hawaii because of the high labor requirements. Potential young farmers are not attracted by the taro industry. Increased interest among farmers in mechanization of planting and harvesting the crop has thus been enhanced by an inability to meet consumer demand. This study was therefore undertaken to evaluate the influence of three land preparation methods (flat culture, ridges 13 and 26 cm high), three plant spacings (20, 30 and 40 cm; row spacing 100 cm) and two planting depths (8 and 14 cm) on performance of taro in relation to mechanization.

Ridge culture produced significantly greater amount of solids in corms and cormels than conventional flat culture at 12 months.

There was a significant effect of planting depth on corm and cormel lateral growth. Deep planting might therefore require a broader blade or auger for mechanical harvesting. In relation to this was the finding that corms and cormels under deep planting had a longer and slender posterior than those under shallow planting. Furthermore, cormels under deep planting had a hook-like base. Both of these traits would be undesirable to consumers if corms were to be sold fresh.

The highest vertical force required to pull a taro hill for land preparation method was 48.2 kg with the 26 cm ridge height culture; whereas for planting depth, it was 47.6 kg at the 14 cm depth.

The effects of land preparation method and planting depth on yields at 12 months were not significant. However, the highest yield, 62.4 metric ton/ha, was obtained under the 13 cm ridge height culture. Total

yields (metric ton/ha) for the 25,000, 33,333 and 50,000 plants/ha were 49.4, 55.8 and 66.0 respectively and were significantly different from each other. None of the interactions were significant for yield except for spacing x planting depth.

The effects of three water regimes (continuous flooding = 0; water drained 2 and 4 months before harvest = 2 and 4 respectively) on taro yield, ease of harvesting and corm quality in terms of fermentation, flavor and color were also studied. Total yields for the three treatments, 0, 2 and 4 were 80.0, 75.5 and 57.3 metric ton/ha respectively whereas man-hours/ha required to pull out taro was as follows: 0 = 305.6, 2 = 844.4 and 4 = 300.0. For the removal of roots, man-hours/ha were 0 = 938.9, 2 = 1372.2 and 4 = 961.1. Poi from treatment 0 had a slightly faster rate of fermentation, measured on the basis of pH changes, than that from treatments 2 and 4; whereas poi made from treatment 2 had a pinkish to reddish color compared to the somewhat grayish color of poi from treatments 0 and 4. Results of poi flavor and color were not significant but there was a slight preference for poi made from treatment 0, the control.

Results of pot studies (Greenhouse + 51% shade; Outside + 45% saran shade; Full sun; Planting depth - 5 and 10 cm; Type of huli - main and sucker) showed a significantly higher yield of corms and total yield under greenhouse and saran than full sun.

Within a given level of shade, total yield was significantly higher for main than sucker hulis for pots in the greenhouse and full sun. In relation to planting depth, corm yield was significantly higher under deep than shallow planting for outside + 45% saran shaded pots. Cormel yield was significantly greater under shallow planting than deep planting for pots in greenhouse and full sun. Shallow planting also significantly out-yielded deep planting for total yield but only for pots in full sun.

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INTRODUCTION

Colocasia esculenta (L) Schott is an important carbohydrate root crop which is not only a basic food crop but also can be utilized commercially. It is a monocot in the family Araceae of the order Arales. Common names for *Colocasia esculenta* vary from one culture to another. In Hawaii it is called taro. In West Africa it is known as cocoyam; whereas in the West Indies it is known as eddoe. Allen and Allen (1933) cited Barrett as approximating a figure of 300 different varieties. In Hawaii the variety Lehua is the most important commercially. It is named after its reddish corm and bright red piko (juncture of petiole and blade) suggestive of the crimson bloom of the Ohia tree (Handy, 1971; 1972). The dasheen is probably the best known of the taros grown in temperate areas. It is thought (Allen and Allen, 1933) to have been derived from the term 'de Chine,' signifying that this variety originated in China. Records of its cultivation date back (Payne, Ley and Akau, 1941) to 100 B.C. It was in Egypt by the beginning of the Christian era. For convenience, *Colocasia esculenta* will be called taro in the remainder of this report.

Taro can be grown both on dryland and under flooded conditions, probably because of an ability to transport oxygen from the leaves to the roots. This has been demonstrated in rice (Cherin *et al*. 1968) through isotopic studies. Taro can also be grown under rather adverse conditions. For example, taro has been used as the initial crop for reclaiming salt-affected sandy soils under flooded conditions (Plucknett, 1970). Rice has shown similar responses (Dargan *et al*. 1974). These plants may not necessarily be salt-tolerant, but flooded conditions may dilute the salts in the soil. Flooding also desalinates a shallow soil layer to the extent that growth of crops will be possible when roots are superficial.

Labor requirements for production of tropical root crops are generally high. For example, the labor requirement for the production of yams (Coursey, 1967) in Nigeria, Ghana and Trinidad is 360, 456 and 280 man-hours per ton respectively, as compared to 7.6 to 16 man-hours per ton for production of Irish potatoes in the United Kingdom. In Hawaii, growing taro under flooded conditions makes mechanization difficult, resulting in higher labor costs. Higher labor costs in part account for the higher cost of both taro and its finished products when compared to other commodities such as rice and potatoes. Since taro is a staple food in parts of Syria, India, China, East and West Indies and all of the Pacific Islands (Payne et al. 1941), this high cost of production is an important factor in the economy of these less developed countries.

Within the past few years there has been a gradual decrease in taro acreage due primarily to the high requirements for hand labor (Table 1). Planting and harvesting by hand requires much stooping and long hours in the flooded fields. Ninety percent of the taro crop produced in Hawaii is flooded and many young potential farmers dread the idea of wading in the mud. Traditionally, plots have to be puddled and levelled to conserve water, control depth and maintain fresh water circulation within the patches during the entire period of crop growth. Prospects of mechanization are therefore hindered by these cultural practices. Mechanically powered equipment specifically adapted to wetland conditions is rare. The market for fresh taro and poi in Hawaii is too small to

Table 1. Number of Taro Farms, Acreage, Marketings, Price, Value and Shipments of Poi from Hawaii from 1964 - 1974[1/]

Year	Farms	Crop acreage	Marketings	Farm price	Value of sales	Shipments of poi to the mainland U.S. (canned, frozen and fresh)
	Number	Hectares*	455 Kg*	Cents/Kg*	$1,000	455 Kg*
1964	162	190	4,216	13.4	564	73
1965	162	178	4,309	13.2	573	65
1966	150	162	4,086	13.6	561	68
1967	148	162	3,707	15.6	579	57
1968	141	170	4,155	16.3	676	43
1969	138	170	3,911	17.2	671	33
1970	132	190	3,889	18.9	736	35
1971	128	194	4,018	19.6	787	29
1972	123	186	4,100	18.5	758	19
1973	127	186	3,854	20.7	798	28
1974	127	186	4,016	22.4	900	18

*Converted into metric system: 1 Ha = 2.47 acres; 455 kg = 1,000 lbs; cent/kg.

[1/] Source: Statistics of Hawaiian Agriculture (U.S.D.A.) 1974.

justify extensive expenditures to develop equipment specifically designed for taro production. However, if a Mainland market could be developed for taro as dietary foods, the cost of mechanization may be justified. Taro in the form of poi or flour has an excellent potential for individuals having hypertension, allergies, or gastrointestinal disorders (Rada, 1952).

One of the basic problems in harvesting taro corms is that unlike most other root crops whose real roots wither and die at time of harvest, taro continues to produce an extensive root system, even at time of harvest, particularly under flooded conditions. Another problem is that main corms and cormels tend to adhere particularly in soils high in clay content. Both of these factors increase the energy required to lift out the corms. Separation is also tedious. Recent work by Ezumah (1972) suggested that even though ridging has no advantage over the conventional flat culture in corm yield, it may nevertheless be necessary for mechanical harvesting since root spread and growth are less extensive at time of harvest.

In order to adapt farm equipment used for other crops to taro production, a firm soil surface is necessary to facilitate easy movement at planting time. Plot preparation can be done with powered tractors, disc harrows and rotovators which would eliminate puddling of the soil. Plots can then be flooded immediately after planting. The question of whether such changes would affect yields needs to be considered. Thus, this shortage of labor causes an inability to meet market quotas and has led to increased interest in mechanization, with particular reference to planting, harvesting and separation of corms and cormels. This research is therefore designed to conduct crop management practices related to mechanization of taro culture. This would involve obtaining information on:

1. Crop morphology and yield components as related to mechanization
   a. leaf, sucker, corm and cormel yields
   b. maximum lateral and vertical growth of corms and cormels
2. Number of pounds required to lift a taro hill from the ground
3. Nutrient status in corms and cormels
4. Taro quality with respect to poi fermentation, flavor and color.

Further pot studies were designed to shed more light on leaf, sucker, corm and cormel development.

LITERATURE REVIEW

Tropical root or tuber crops such as cassava (*Manihot esculenta*, Crantz), sweet potato (*Ipomoea batatas* L. Lam), new cocoyam (*Xanthosoma sagittifolium* L. Schott), old cocoyam or taro (*Colocasia esculenta*) and yam (*Dioscorea spp*. L) play an important role in the daily diet of inhabitants in the sub-tropical and tropical areas (Rasper, 1967; Jeffers and Payne, 1967). Their contribution to the human diet in Africa and South America, for instance, is comparable, to that of cereals (Leslie, 1967).

However, these crops have not received much attention nor a favorable image. Their yields are sometimes described as low; and even though this is often the case under peasant farming, their genetic and agronomic capabilities still await untapping (Coursey *et al*. 1970). In fact, under good management practices such as fertilizer application, yields of 58+ metric tons/ha have been obtained (de la Pena, 1967) in Hawaii under flooded irrigation and by adding 1120 kg/ha N. Moisture content is also considered to be high, but one needs to stress the fact that much more of the dry matter accumulated by these crops serves as human food. Furthermore the useful portion is obtained without sexual process involved and yields may be significantly high or even maximum before sexual maturity. Some of these crops like cassava and taro can be stored in the ground for lengthy periods without deterioration.

Alexander (1967) reported that in Trinidad, the Irish Potato is preferred to other starchy root crops by virtue of (a) variety of presentation on the table, (b) ease of availability, (c) taste and (d) economic reasons. Other stigmas accorded to root crops are in relation to using them in their forms: irregular shape, hard to peel and sometimes too large or bulky both for the housewife and for transportation. They are also relatively expensive, pound for pound compared to other sources of carbohydrate, while at the same time they can only be served in a few forms. Eating habits of people are difficult to change, but if we can increase the ways of preparation of these crops, it is very likely that we would increase their demand.

Root crops may be quite acceptable as a major source of food, particularly in tropical areas, provided they are supplemented or fortified with enough quantities of high-quality protein or synthetic amino acids. The Irish potato has been well studied, largely in temperate countries. Overall farm yields under British conditions have essentially doubled over the last 70 years (Coursey and Haynes, 1970). Tropical root crops, on the contrary, are virtually untapped, and it is not unreasonable to expect that similar increases could be achieved with root crops such as taro, cassava, or sweet potato.

Importance of Taro as a Food Crop

Taro can be cooked and eaten like Irish potatoes, sweet potatoes, yams or cassava. However, it cannot be eaten raw because of its needle-like crystals of calcium oxalate called raphides. Caloric and carbohydrate values of taro are 130 and 31.1/100g respectively (Derstine and Rada, 1952). This is higher than baked white potatoes (98 and 22.5 g) and brown rice (102 and 22.0g), but less than cooked white rice (201 and 44.0g). Calcium content is higher than that of white potatoes and rice, whereas its vitamin content of thiamine, riboflavin and niacin is approximately equal to that of cooked white potatoes but higher than that of rice. Phosphorus and protein amounts are lower than rice.

The chief acid-forming elements in foods are S, P and Cl, whereas the alkaline-forming ones are Na, K, Ca and Mg (predominant in fruits and vegetables). Alkaline-forming elements exceed acid-forming ones in both taro and poi. Jones et al. are cited (Derstine and Rada, 1952) as implicating that a diet that provides proper acid-base balance with an alkaline excess provides sound teeth.

Approximately 98.9% of taro starch is digestible by humans (Allen and Allen, 1933) because of the small size of the granules. Maximum, average and minimum granule diameters are 0.0093, 0.0045 and 0.0025 mm respectively (Payne et al. 1941). This is about one-tenth the size of Irish potato starch granules but about the same size as that of rice. Several products can also be made from taro corms:

1. They can be made into flour which can substitute for about 20% of wheat flour in baking with a resulting increase yield due to its higher water absorptive ability which improves the quality of baked products (Payne, Ley and Akau, 1941). As high as 60% of the flour in cookies can be taro (Payne et al. 1941).
2. Breakfast foods such as flakes, shreds and grits potentially can be made from taro.
3. Payne et al. (1941) indicated that a highly palatable beverage that readily mixes with milk and water can be made from cooked taro by incorporating flavoring and sweetening agents.
4. Like potatoes and other starchy foods, taro corms and leaves can be canned, whereas in Hawaii, taro is commonly eaten as poi - a food processed by pounding or grinding cooked taro

corms, mixing with water and allowing it to ferment. Both poi and boiled taro can be used as hypoallergic foods partly because of their lower protein content (less than 2%) compared to 2% in yams and potatoes (Standal, 1970).

In Hawaii poi is classified into three consistencies by regulation of the Territorial Board of Health (Derstine and Rada, 1952):

1. Poi containing at least 30% total solids
2. Poi containing less than 30% but not less than 26% solids and
3. 'Readily mixed poi' containing less than 26% but not less than 18% solids.

Acid Fermentation of Poi

There are two phases in the acid fermentation of poi (Allen and Allen, 1933; Standal, 1970). The first phase is predominated by lactic acid producing bacteria. Acidity increases up to the sixth day. For instance, a drop in pH from 6.3 to 4.5 during the first 24 hours of fermentation has been noted (Allen and Allen, 1933). The second phase starts from the third to the sixth days and is marked by presence of yeasts, mycoderms and oidia that cause no appreciable changes.

Amin is cited (Standal, 1970) as suggesting amylose to be the predominant starch in taro. That during its fermentation (Taro ——> Poi) amylose is converted to amylopectin with smaller amounts of dextrine and glucose. A temperature of 37 C is suggested (Allen and Allen, 1933) during fermentation for a uniform poi product. Poi fermentation is similar to that of souring of milk or preparation of sauerkraut (Derstine and Rada, 1952) but is stopped by heat and freezing treatments.

In the fermentation of cassava, starch is converted into lactic and formic acids by Corynebacterium manihot or other lactic acid bacteria with a subsequent decrease in pH to about 4.25. Interestingly, poi undergoes self-purification during its fermentation.

Importance of Mechanization

Mechanization is usually initiated to increase productivity of existing agricultural holdings and schemes, particularly where labor is limited. But we need to be sure that the introduction of machinery is financially feasible under the framework of the existing economic system. However, when taro is considered, there are a number of techno-economic factors which influence or limit the degree of mechanization (Pothecry, 1970): (a) the small size of average holdings, (b) problems associated with efficient operation of machinery, (c) weed control problems, particularly against competing grasses which may influence planting techniques, (d) consumer acceptability of varieties that are bred for fully mechanized harvesting, (e) the fact that taro, like rice, where grown as a mono-crop, must support the whole cost of machinery which is used and (f) the number of people depending on taro as a food and the negative attitude of potential young farmers towards the taro industry.

Perhaps the most important factors are irrigation and drainage, weed control and consumer acceptability, since these are often crucial factors determining whether more sophisticated types of machinery can be introduced. However, mechanization per se has several obvious merits: (a) it helps to increase crop yields because of more efficient land preparation techniques and fertilizer incorporation, (b) facilitates expansion of crop production, (c) encourages the establishment of domestic as well as foreign industries due to large acreage and (d) reduces labor requirements by permitting simultaneous operations with rototiller attachments.

Mention has already been made of the fact that rice culture is similar to taro, in that both can be grown under flooded and dryland regimes. With this background in mind, a study of the various aspects of rice production will suffice to illustrate possibilities of taro mechanization. Paddy grown rice is by tradition almost exclusively transplanted in order to ensure a high plant population as well as permitting weed control by flooding the fields up to the time of planting (Pothecary, 1970; Smith, 1970). Dryland planting using seed drills has so far been limited to those irrigated areas in drier climates such as Australia, the United States, and the Mediterranean, where the climate allows dryland preparation and weed control operations up to the time the land is flooded. In Hawaii, commercial fields of taro are plowed, disced, and harrowed with powered agricultural equipment, as in dryland culture. Planting and harvesting have been done with a tomato transplanter and with potato or sugar beet diggers with minor adaptations; unfortunately they have had little success.

Flooding in Relation to Taro Culture

In many areas of the tropics and subtropics, taro is grown under dryland conditions. Rainfall may be the only source of water supply. In a review of dryland taro culture, it was (Plucknett _et al_. 1970) indicated that rainfall under which taro is grown ranges from about 100 cm in parts of Burma to over 500 cm per annum in some areas of India. Yields of taro are usually higher in paddy than in drylands. Lower yields have consistently been reported for dryland taro (Kagbo et al. 1973; Plucknett, 1970; de la Pena, 1967): Hawaii = 40 tons/ha; Malaya = 7.8-8.9 tons/ha; India = 22-30 tons/ha; Trinidad = 4.5 tons/ha; and West Africa = 3.5-7.8 tons/ha. Flooded taro has produced 58 metric tons/ha in Hawaii. Dryland taro also matures earlier than flooded taro and produces fewer number of suckers. However, diseases of the corm or roots are common in wetland taro, although losses due to these diseases are insignificant in Hawaii.

In rice, paddy culture is also reported (De Datta et al. 1970) to affect the physical character of the plant, nutrient status of the soil, and extent of weed growth. Plant height, for instance, is directly related to depth of water in the field. Higher yields of rice under continuous flooding have also been consistently better than dryland culture. These lower grain yields under these conditions have in part been attributed to (a) lack of suitable varieties, (b) irregular rainfall distribution, (c) problems of weed control and (d) poor insect and/or disease control; whereas higher yields under flooded culture might be due to (a) better soil-plant water relations, (b) higher tissue hydration, (c) efficiency of water use and lower evapotranspiration rate and (d) higher nutrient availability and uptake (Tomar and Ghildyal, 1973).

Effect of Flooding on the Soil

The state of several important nutrients is altered upon flooding a soil because of oxidation-reduction processes brought about by absence of oxygen. Flooding also changes soil temperature by changing soil color, absorption of heat and by affecting specific heat conductivity of the soil.

Physical and Biological Changes

Puddling and flooding a soil breaks down structural aggregates and pore spaces, thereby improving mechanical strength of the soil by removing impedence to roots. About 6-10 hours after flooding a soil, oxygen level drops to about zero (Villegas et al. 1970; De Datta, 1970; Patrick and Mikkelsen, 1971). This brings about an increase in other gases (1-2% CO_2, 10-95% N_2, 15-75% CH_4 and 0-10% H_2) due to microbial activity. The proportion of these gases depends on the soil and other environmental conditions, microbial inhabitants and nature of organic and inorganic materials present as substrates (Patrick and Mikkelsen, 1971).

Two distinct zones are generally created upon flooding a soil (De Datta, 1970; Patrick and Mikkelsen, 1971):

1. The top 1-2 cm oxidized zone caused by diffusion of atmospheric oxygen through the water and to oxygen from various photosynthetic hydrophytes in the water. This thin layer supports aerobic microorganisms and certain oxidized nutrient ions such as $NO_3^=$, $SO_4^=$, Fe^{+++} and Mn^{+++}. To some degree it resembles an unflooded soil.
2. The lower anaerobic zone is dark or blue gray in color because of reduced chemical ions such as manganese and iron and products of anaerobic respiration. It has low Eh values and anaerobic microorganisms are present in it (Ponnamperuma, 1955). This is the zone of root development in rice.

The usual soil aerobic and facultative anaerobic microbes (bacteria, actinomycetes and fungi) steadily decrease about 48 hours after flooding a soil due to lack of oxygen (Patrick and Mikkelsen, 1971). Growth of chlorophyllous photosynthetic algae is also favored. These organisms are generally native to most soils, and environments with adequate sunlight and moisture promote their growth. They reduce CO_2 to various carbohydrate substances in presence of light with a release of molecular oxygen.

Under anaerobic conditions, facultative and obligate anaerobes produce energy from oxidation of organic compounds in the process of anaerobic fermentation. Lactic acid, a first product of this process, is converted to acetic, formic and butyric acids. These products, in addition to alcohols, CO_2, CH_4, and H_2, are derived from carbohydrates (Patrick and Mikkelsen, 1971), while ammonia, H_2S and amines are derived from proteinaceous materials.

The amount of energy released also differs between aerobic and anaerobic decomposition. The latter produces less energy and less utilization of substrate carbon, hence a slower rate of organic matter decomposition.

pH and Plant Nutrients in Flooded Soils

A change in pH towards neutrality (6.5-7.5) occurs in most soils after flooding (Coleman and Thomas, 1967; Patrick and Mikkelsen, 1971). In acid soils, pH generally increases whereas in alkaline soils it decreases. This points to a pH buffering capacity of flooded soils around neutrality by producing substances like Fe, Mn, and Al in the form of hydroxides, carbonates and carbonic acid, formed as a result of reduction reactions brought about by the absence of O_2. Increase in pH is caused by precipitation of aluminum hydroxide, reduction of ferric iron and adsorption of ferrous iron by clay (Cate and Sukhai, 1964).

This reaction involves a release of one hydroxide ion for each iron reduced which brings about a "self-liming" effect (Coleman and Thomas, 1967):

$$Fe(OH)_3 + e \longrightarrow Fe(OH)_2 + OH^-$$

Nitrogen:

Inorganic nitrogen is generally present both as nitrate and ammonium in most soils. Upon flooding a soil however, there is an accumulation of ammonium and instability of nitrate (Patrick and Mikkelsen, 1971). Most of the ammonium nitrogen is adsorbed on cation exchange complex except in reduced soils. There are also large amounts of ferrous iron and manganous manganese on the exchange complex. Under such conditions, more of the ammonium will be in soil solution. Uptake by plants, fixation in silicate crystal lattices, loss by volatilization and oxidation by Nitrosomonas are processes that remove both forms of ammonium.

Nitrate, on the contrary, readily dissolves in the soil solution.

Under conditions where a soil is not flooded immediately after plowing, nitrate-N is formed as in dryland conditions, so that when the soil is later flooded, the nitrate is changed in gaseous form (N_2 and N_2O) and lost into the atmosphere. Therefore, nitrate-N fertilizers are not appropriate for flooded rice. Denitrification is also reported (Villegas et al. 1970) to occur in rice if ammonium forms of fertilizer applied at time of last harrowing before transplanting are not incorporated into the soil:

$$NH_4\text{-}N \xrightarrow[\text{oxidized zone}]{\text{microbes}} NO_3$$

moves into the reduced zone where it is transformed into NO_2- and lost.

Therefore, ammonium-forming N fertilizers such as $(NH_4)_2SO_4$, urea and $(NH_4)_3PO_4$ are applied under flooded conditions.

Investigations into factors affecting auxin degradation indicated that growth responses in rice suggest differences in auxin metabolism (Senewiratne *et al.* 1961). Plants grown under non-flooded conditions (high in Mn) have:

1. a low catalase activity and
2. a high peroxidase activity which favor accelerated degradation of auxin:

$$H_2O_2 + \text{IAA} \xrightarrow{\text{Peroxidase}} \text{oxidized IAA} + H_2O$$

It was therefore suggested that high Mn levels in plants under non-flooded conditions affect IAA oxidase mechanism which results in retardation of growth and depression of grain yield.

Phosphorus:

Phosphorus exists both in organic and inorganic (Al, Ca and Fe phosphates) forms. Organic forms become slowly available to plants upon decomposition of organic matter. Its fixation and release in the soil is influenced by (a) amount and activity of Al, Fe, Ca and Mg, (b) amount of clay present, (c) pH of the soil and (d) oxidation-reduction state of the soil. Under continuous flooding, phosphorus solubility is increased due to reduction of ferric to ferrous phosphate and to hydrolysis of phosphorus compounds.

Potassium:

Flooding a soil has little effect on status of potassium as compared to either N or P. However, release of ferrous and manganous ions and production of NH_4^+ ions may displace some K^+ ions from exchange complexes to the soil solution (Patrick and Mikkelsen, 1971), thus increasing its availability to plants.

Water Management and Fertilizer Use

Soil in a reduced state, as a result of flooding, is desirable because of its effect on plant nutrients: (a) oxidation-reduction processes brought about by anaerobic conditions, (b) changes in pH as a result of oxidation-reduction changes in soil, (c) increased availability of nutrients because of greater mobility in the flooded soil-solution, (d) excess water serving as a diluent causes greater solubility of some elements (B, Mo, Co, Cu and Zn) because of increased solubility of sparingly soluble compounds and (e) precipitation with sulfide (Villegas et al. 1970; Patrick and Mikkelsen, 1971).

Flooding also controls weeds, solves the problem of moisture as a crop limiting factor and provides a favorable microclimate for plant growth. It enhances nitrogen-fixation by blue-green algae and other microorganisms (Serewiratne et al. 1961), while work (Villegas et al. 1970; Senewiratne and Mikkelsen, 1961) on rice suggested that differences in availability and forms of N, Fe, Mn and P both native or added as fertilizers to the soil, alone or in combination, might determine the physiological basis of higher crop yields under flooded soils.

There was, for instance, a release of P due to greater solubility of Mn, Fe and Al (Ca, Mg and Zn frequently depressed), whereas under upland aerated conditions, P was chemically bound by silicate clays. However, in terms of P content of foliage, Cherian et al. (1968) have suggested that application of P has greater effect than flooding, so that beneficial effects of P were obtained by fertilization of plants grown under non-flooded conditions. All sources of P also increased uptake of Mg and K. Availability of P has also been associated with increased uptake of N, increased pH of acid soils and decreased pH of alkaline soils upon flooding. Increased yield of rice due to Si was attributed (Pande *et al*. 1970) to promotion in translocation of P in plants while retarding uptake of Fe and Mn by increasing oxidizing power of rice roots. Puddling a soil also increases availability of Si due to exposure of clay fractions to the surface. Toxicity of Fe has been found (Villegas *et al*. 1970) to be reduced by liming, irrigating and draining intermittently and application of S-bearing materials.

Plant Spacing

Plant spacing in taro depends on a number of factors: (a) taro variety, (b) amount of sunlight, (c) type of soil and (d) length of the growing season and other cultural practices employed. Nevertheless, it is essential that all exposed vegetative parts receive adequate sunlight. Optimum spacing, to a large extent, is probably dictated by the amount of sunlight, water and nutrients available. In Hawaii, the spacing commonly used is 45 x 60 cm (35,815 plants/ha) or 60 x 60 cm (26,900 plants/ha). In valleys with less amount of sunlight due to clouds and high rainfall, spacing is generally wider, as much as 90 x 90 cm (Plucknett *et al*. 1971), whereas in paddy cultures where there is abundant supply of moisture, spacing is closer.

In many countries, particularly in West Africa, root and tuber crops such as cocoyams, yams, cassava and sweet potatoes are planted on mounds in a haphazard manner (Ezumah, 1972), spacing is difficult to estimate. A spacing of 90 cm between hills is reported for taro (de la

Cruz, 1970) in the United States Trust Territory, whereas in West Africa a 90 x 90 cm (11,950 plants/ha) spacing is reported by Bates (1957). Working with mustard, Singh and colleagues (1971) found no significant difference in row spacing either at 45 or 90 (cm) between rows. Whereas, in a study comparing 1.2 x 1.8 ft; 0.8 x 1.8 ft and 0.6 x 1.8 ft spacing in India, the 1.2 x 1.8 ft spacing gave highest total yields (Plucknett *et al.* 1970). In general, spacings are wider under dryland conditions than under wetland conditions. Recent work in Hawaii (Ezumah, 1972) indicated highest corm yields of 84 ton/ha at 54,000 plants/ha under flood irrigation at 13 months. Enyi (1967b) states that aside from better drainage, superiority of ridges over flats was only observed when extra large setts (sett = planting material in *Xanthosoma*) were used as planting material. Young setts had a higher concentration of P and therefore sprouted earlier. Yields have also been reported (Plucknett *et al.* 1970) to be highly significantly correlated with both plant height and leaf area since there was also a significant correlation between plant height and leaf area.

Depth of Planting

Depth of planting and depth of coverage are quite important and should vary with the existing soil conditions. Information regarding depth of planting is somewhat lacking in the culture of root crops. However there is available information in the literature particularly for seeded crops and weeds. For instance, in a study of honey mestique seedlings, maximum emergence was reported at a planting depth of 0.5 cm and 27 C soil temperature (Scrifres and Brock, 1972). Average time required for emergence of seedlings at this temperature increased with depth of planting. Dawson and Burns (1962) on the other hand, reported that in barnyardgrass, green foxtail and yellow foxtail, seedling emergence in spring or greenhouse was greatest in the most shallow depths (½ or 1 inch) and decreased with increased depth of planting. Murphy and Arny (1939) also reported a greater emergence from the ½-inch depth of planting than from surface planting of legumes and grasses under field conditions of Forgo silty clay loam and Merrimac loamy fine sand.

The reported delayed emergence by Scrifres _et al_. (1972) was reflected in reduced seedling vigor. These workers also observed a direct relationship between total seedling length and planting depth. Longest seedlings (root + shoot) emerged from the 0.5 or 1-cm planting depths. Root:shoot length ratio of seedlings that emerged from 0.5 cm depth was 5:1 (Scrifres and Brock, 1972). Root length decreased with increased depth of planting, indicating that emergence of seedlings from the 1 cm depth occurred at the expense of root development. Seeds that were placed on the surface of the soil germinated, but their seedlings did not survive. Similar results for barnyardgrass, green foxtail and yellow foxtail were reported by Dawson and Burns (1972).

Planting reproductive roots of _Sonchus arvensis_ at depths ranging from 2.5 to 30 cm and lengths from 2.5 to 24 cm showed maximum growth of shoots and new roots at depths ranging from a few cm to 5 to 10 cm below the soil surface (Hakansson and Wallgreen, 1972). Also more aerial shoots seemed to develop per unit length from shorter than from longer root pieces. Planting shorter roots at greater depths also tends to decrease the number of established aerial shoots and the production of new thickened roots. This decrease is reported (Hakansson _et al_.

1972) to be accelerated in the presence of interspecific competition.

In soils with good tilth and good drainage characteristics, planting of sugar cane stalks ("seed pieces") in deep furrows (10 to 16 inches deep) is desirable (Humbert, 1968), particularly under furrow-irrigated conditions; whereas planting in shallower furrows, 6 to 12 inches deep, is desirable with sprinkler irrigation or unirrigated cane culture. Since deeper coverage delays emergence and often increases "seed" mortality, "seed" should be covered with no more than 1 to 2 inches of soil (Humbert, 1968). Humbert (1968) cited Borden as obtaining germination percentages of 96, 93, and 69 respectively in cane "seed" covered with 1, 3, and 5 inches of soil in Hawaii. However, the surface soil should be kept moist by frequent, light irrigation under shallow depths of planting. Cultural practice of throwing soil around the growing plant also places the zone of maximum concentration of roots at a deeper depth.

Thus based on these findings, crop emergence in relation to depth of planting is, among other factors, a function of the crop soil temperature, type of soil and soil moisture content. If the depth of planting that gives maximum total emergence is used for a given crop species, it would be possible to obtain a desirable stand (Dawson and Burns, 1962) by planting less seed per acre.

Fertilizer Requirement

Response of taro to fertilization varies with the type of management practice employed (Kagbo, Plucknett, de la Pena and Fox, 1973). Published information on its mineral nutrition is scanty, but the few available publications suggest that it responds well to fertilization, particularly when grown on leached tropical soils (Hodnet, 1958; de la Pena et al. 1972). In Hawaii, for instance, lowland taro responds most to nitrogen while dryland taro responds most to phosphorus and then to nitrogen (Plucknett et al. 1970). The lesser response to applied P may partly be explained by its chemical release under reduced state of flooded soils. Dryland taro yields of 40 tons/ha harvested at 15 months with 560 kg/ha P applications at the Kauai Branch Station, Hawaii, have been reported by de la Pena (1967). These yields are greatly superior to those reported (Plucknett et al. 1970) from Malaya, Trinidad, India and West Africa, where yields are about 7.8-8.9; 4.5; 22-30 and 3-7 metric tons/ha respectively under various cultural practices. In one of de la Pena's investigations (1967), the greatest yield of 58 metric tons/ha of flooded taro was obtained by adding 1120kg of N/ha.

Requirements of taro for K are rather high and yields are often related to its application. K increased sugar production in the leaf blades and starch in the corms. Luxury consumption of K and P by taro has been reported (Plucknett et al. 1970; de la Pena, 1967) both under lowland and dryland cultures when concentration of K and P in the petioles approaches 10.3% and 0.6% respectively on a dry weight basis. Increased yields of flooded taro and rice due to K fertilization varies from no response to moderate depending on: (a) soil situation, (b) amount of K coming from irrigation water, (c) cropping intensity, (d) level of yield, and (e) rice straw management. Much of the K used by rice crop (Villegas et al. 1970) is in the roots and straw, so that returning these to the soil means providing more potassium for the next crop. The two main sources of potassium are K_2SO_4 and KCl. Their efficiency is about equal in terms of plant recovery and yield capacity

(Patrick and Mikkelsen, 1971); preference of KCl over K_2SO_4 is partly because it is cheaper and the fact that sulfate may be reduced to hydrogen sulfide in some tropical areas which may be toxic to plants. Among other things, potassium aids in translocation of carbohydrates, organic acid and stomatal regulation, increases resistance of plants to pests and influences the activity of other nutrients (Patrick and Mikkelsen, 1971; Villegas et al. 1970).

Very little information on the timing of fertilizer applications in taro is known. Except for P, split applications have been recommended in Hawaii (Plucknett et al. 1970). Root and tuber crops initially have a rapid period of vegetative growth extending up to about five months after planting, followed by a root or tuber development period. Since the latter is dependent on carbohydrates produced in the leaves, adequate applications of nutrients during the vegetative period is necessary to make sure vegetative conditions are optimum. The assumption is made that by applying fertilizer at planting and at 2 and 4 months after planting, a steady supply of nutrients will be available during the vegetative period of growth in taro. This will provide maximum conditions for development of leaf areas as well as leaf conditions that are optimum for photosynthesis (Plucknett et al. 1970; Spence, 1970). The concept of split applications also has the advantages of avoiding nutrient loss through leaching as well as avoiding luxury consumption or toxicity.

MATERIALS AND METHODS

Main Field Experiment

The main field experiment was conducted in the Hawaiian Islands near the base of the Wailua Valley, Kauai, from June 1974 to June 1975. This area, once commercial rice fields, is presently used exclusively for experiments on rice and taro by the University of Hawaii. The soil belongs to the Hanalei series of the alluvial soil group and a detailed description of this has been previously provided (de la Pena, 1967; Ezumah, 1972). Soil chemical analysis prior to planting are shown in Table 2.

In general, these values are in agreement with those reported by earlier workers (de la Pena, 1967; Ezumah, 1972) except for Na which is higher in the present study. The pH of most soils generally approaches neutrality upon flooding due to reduction of iron and manganese.

Experimental Design, Land Preparation and Planting

The design of the experiment was a 3x3x2 split-split plot in a factorial arrangement of treatments with 3 replications. Method of land preparation (flat, ridge 13 cm high, ridge 26 cm high), plant spacing (20,30,40 cm) and planting depth (8,14 cm) were variables (Figure 1).

The field was mechanically plowed and disced twice in order to provide good soil tilth and to destroy weeds. Fertilizer was applied at the rate of 500 kg N/ha as urea, 500 kg P/ha as treble superphosphate and 400 kg K/ha as potassium sulfate. The field was then rotovated. All P was applied at time of planting, while only one-third of the N and K was applied at planting. The balance was added in two split applications at two and four months after planting.

Table 2. Analysis of Soil Used in the Experiment (Wailua, Kauai)

pH	4.70
Total N (%)	0.295
Cation Exchange Capacity (me/100g O.D. soil)	29.50
Extractable* Ca (me/100g O.D. soil)	8.05
Extractable Mg (me/100g O.D. soil)	11.88
Extractable K (me/100g O.D. soil)	0.51
Extractable P (ppm)	10.60
Extractable Na (ppm)	1150.00
Extractable Mn (ppm)	22.10
Extractable Cu (ppm)	1.40
Extractable Fe (ppm)	0.05

*All extractable values were done with 1N Ammonium acetate at pH 7.0.

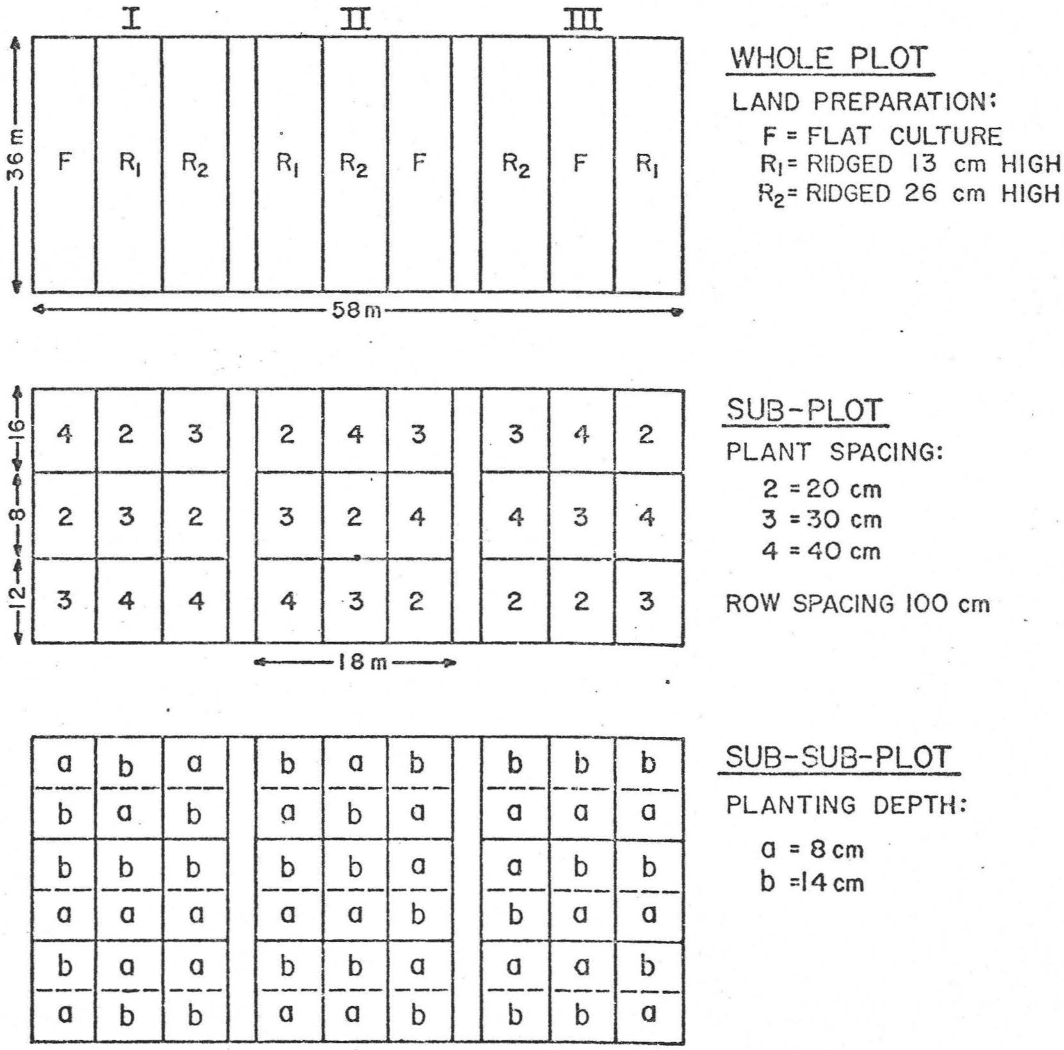


Figure 1. Main field experiment plot outline.

In order to obtain the ridge heights of 13 and 26 cm (measured from the furrow), soil was transferred from the plots which were to have 26 cm ridges to the other plots. Ridges were then constructed with a lister plow. Water was introduced into the plots to settle the soil and to detect high and low spots.

Measuring devices corresponding to the two ridge heights were placed in the furrows and soil was removed or added on the ridges until the desired heights were obtained. The plots with flat culture were levelled with heavy flat pieces of wood tied to a rotovator. The conventional puddling method used by farmers was not used since an earlier study (Ezumah, 1972) suggested that yields under puddle culture were not different from non-puddled culture.

Hulis (the planting material consisting 0.2 to 0.4 cm of the corm or cormel and about 24 cm of the petioles and pseudostem) of taro (Lehua variety) were obtained from experimental plots in Wailua Valley (Figure 2). Hulis were grouped into three sizes: small, medium and large. The small ones were used in the border rows; the medium ones in the third replicate and the large ones in the second and third replicates.

Hulis were planted at depths of 8 to 14 cm. Planting depths were based on the depths of planting found in a commercial farm at Hanalei Valley, Kauai. Plots were flooded throughout the entire experimental period. Weed control was by hand and by chemical means using paraquat.

Plant Sampling

Leaf, of mother plants, and sucker (sucker = any bud from the mother plant or from an older sucker that develops into a plantlet) production were determined from a mean of 10 plants sampled at random

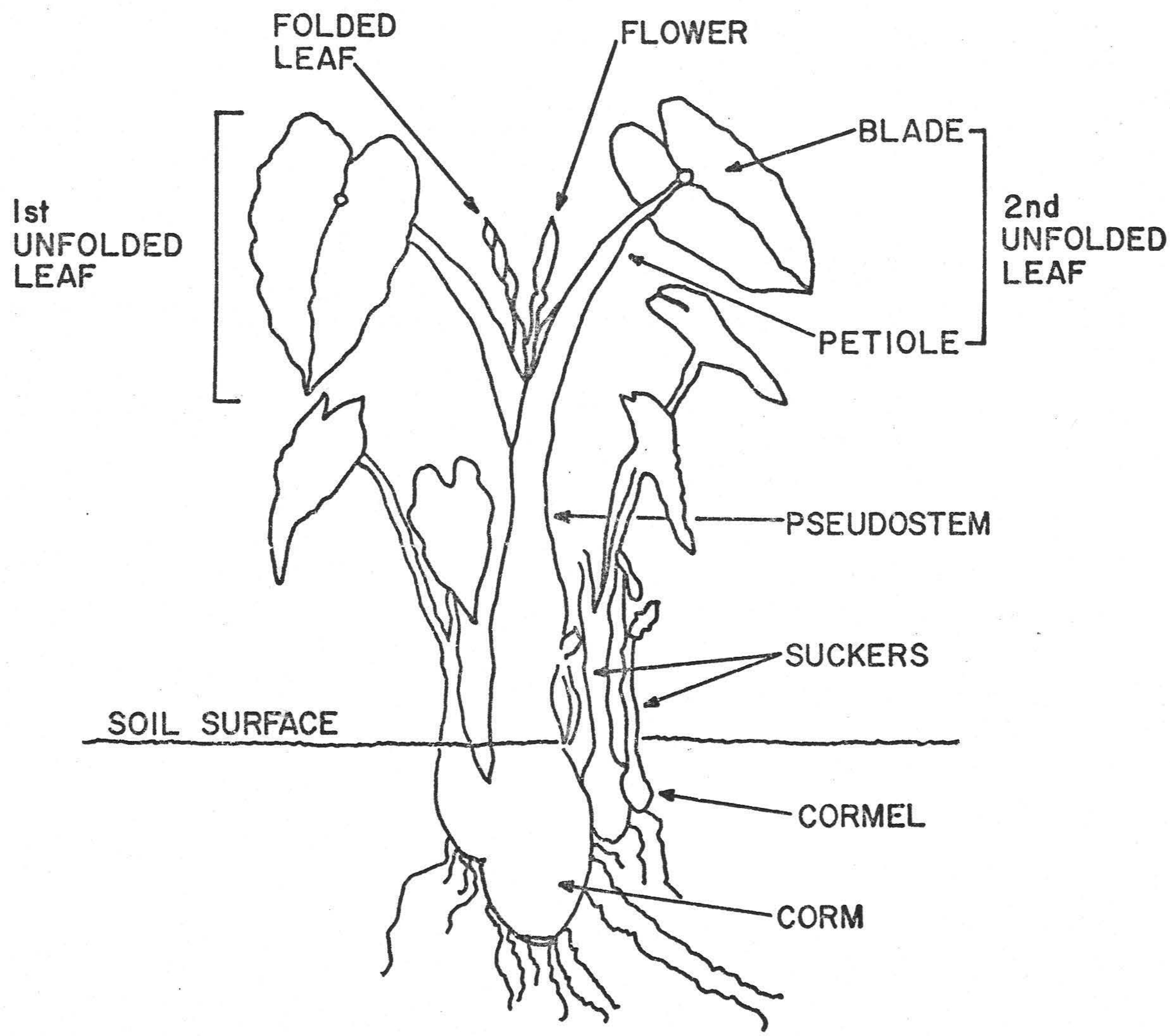


Figure 2. Taro plant

from each sub-subplot at three, five, seven and nine months after planting (Figure 2). All leaves less than 50% necrotic were counted. Leaf area measurements were made on the second unfolded leaf (Chapman, 1964; de la Pena, 1967) (Figure 2). All above ground suckers were counted. Each sucker eventually forms a cormel at some stage of its growth (Figure 2).

Leaf Area Determination

All measurements of leaf area were made only on the mother plant. Leaf area of the edible aroids has been estimated by establishing relationships between estimated area and measurements of various leaf dimensions (Chapman, 1964; Reddy, 1968). In this study, measurements of the dimensions A, B and C (Figure 3) were made on the second unfolded leaf of 10 plants selected at random from each of 54 sub-subplots three months after planting. The measurements from the 54 sub-subplots were averaged to simplify computations. The actual area was determined by tracing the leaf outline on paper. The tracing was cut out, weighed and the area calculated using the weight of a standard area of paper. Several linear and quadratic relationships between the actual area and the linear dimensions A, B, C, $A^2 + B^2$ or their logarithms were evaluated by regression techniques. The equation Log Y = 0.45 + 1.78 Log A where Y is estimated leaf area and A is leaf length in cm was selected because of the very high correlation coefficient ($r = 0.976$, $n = 54$) and the ease of measuring dimension A in the field. None of the several relationships examined resulted in a significantly greater value of r. Dimension A was also used by Ezumah (1972) to estimate leaf area of taro.

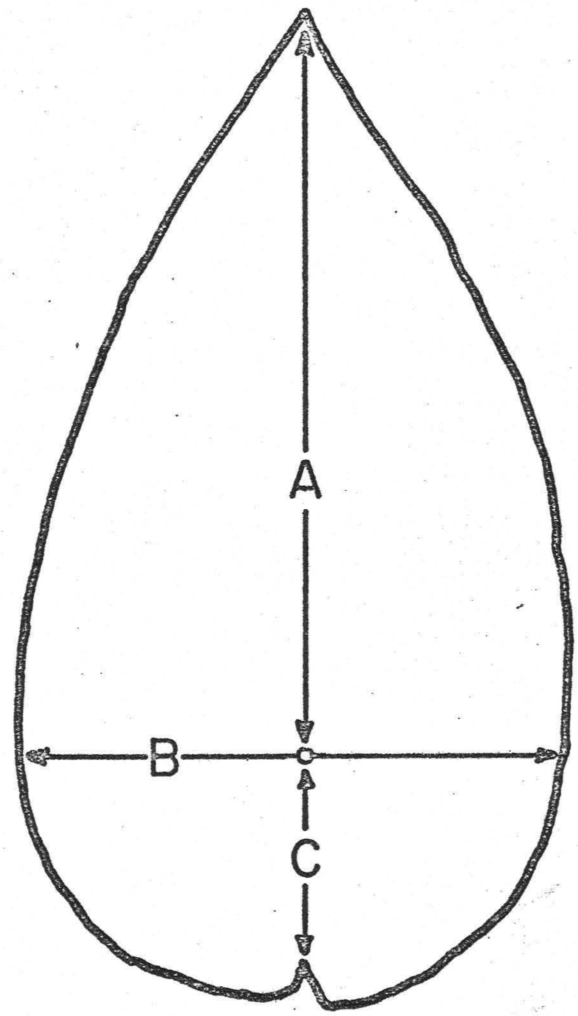


Figure 3. Taro leaf blade showing the dimensions used in leaf area computation.

o = Petiole attachment

A = Length from tip of blade to point of petiole attachment.

B = Total width.

C = Length from petiole attachment to base of leaf.

Mother-Plant Leaf Area Index

Only leaves of the mother plant were counted at time of plant sampling. However, because of the significance of leaf area index (LAI = m^2 of leaf area/m^2 of ground) in crop production, the author was later interested in examining the relationship between LAI at various stages of crop development and total yield for predictive purposes. Since total leaf number (mother plant plus suckers) was unavailable, mother-plant LAI (MP - LAI) was calculated by the equation:

MP - LAI = estimated area/leaf x number of leaves/mother-plant.

Determination of Circumference of Hills

At 10 months after planting, the average circumference of five taro hills (hill = all suckers that have arisen from the original huli; see Figure 2) per sub-subplot was measured by placing a tape around the hill approximately 1.5 cm above the soil surface.

Maximum Vertical Growth of Corms and Lateral Growth of Corms and Cormels

Two representative hills per sub-subplot were selected 10 months after planting for this determination. Using a sharp machete, a straight cut was made through the center of the hill perpendicular to the ridge. After exposing the corms and cormels, the maximum vertical growth of the corms was then measured from the soil surface to the base of the corm (Figure 2). Lateral spread of corms and cormels was determined by measuring them at the point of their maximum width. Plots were drained two days prior to taking these measurements.

Vertical Force

Estimation of force required to lift a taro hill out of the ground was based on a mean of two plants per sub-subplot at 10 months after planting. The device used was constructed in the Agricultural Engineering Department of the University of Hawaii. It consisted of a pulley, a chair-shaped metal frame and two L-shaped metal pieces that were inserted at the base of the corms and cormels. A scale was then attached to the two metal pieces and the pulley operated. The scale was read when the clump of plants/hill was raised out of the soil.

Specific Gravity Determination

Specific gravity of corms and cormels was determined by the displacement method, but modified to use the Principle of Archimedes (Bowers *et al*. 1964). Four representative corms and cormels were selected from each sub-subplot, washed thoroughly and allowed to drain. Individual corms and cormels were then freely suspended in air and in distilled water from a balance by means of a thin, flexible wire. Specific gravity was then calculated from these readings.

Preparation of Corms and Cormels for Total Solid Determination and Chemical Analysis

Corms and cormels used in specific gravity determinations were sliced in half longitudinally and one half peeled, sliced into cubes and oven dried at about 70 C after determining fresh weights. After drying and weighing for total solids (dry matter) determination, samples were finely ground in a Wiley Mill and stored in vials for chemical analysis. Total N was determined by the macrokjeldahl method while the other elements were analysed by x-ray fluorescence (quantometer).

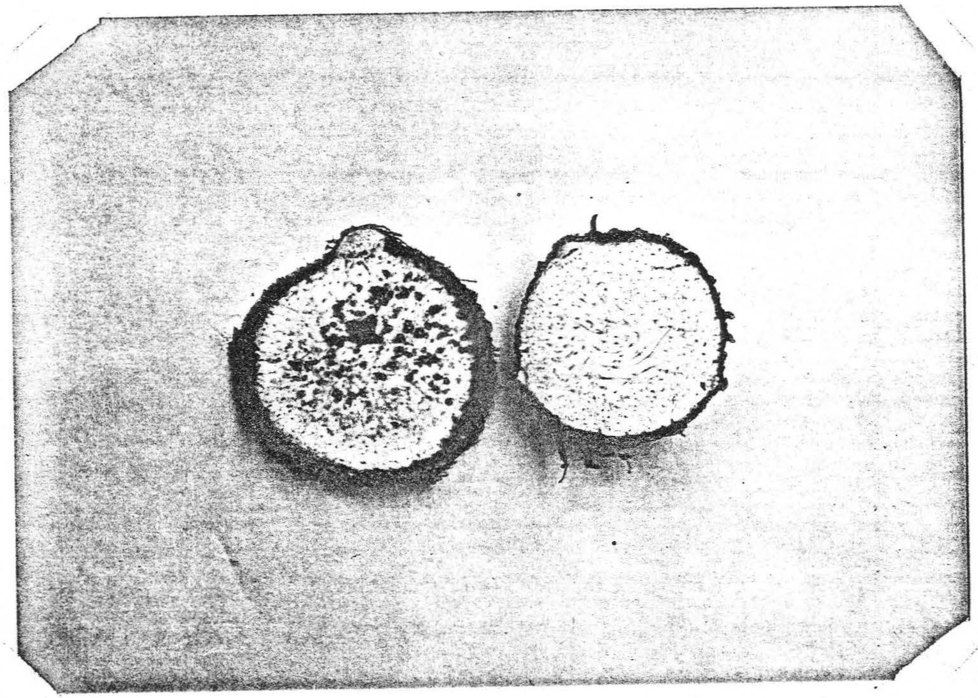
Yield Data

Corm and cormel (Figure 2) yields were determined at 10 and 12 months after planting. Sub-subplots were divided in half and each half randomly assigned to one of the two harvest dates. Ten hills were then harvested per plot. Yields of corms and cormels were determined separately after cleaning. Corms were further separated into normal and diseased since it was observed that quite a few of them had some degree of rot and/or guava seed. (Guava seed or hard rot is characterized by a hardening of the corm or cormel with a number of small hardened brown to reddish spots throughout the corm; see Figure 4). Only normal corms were used for yield at 10 months. Also, some plots did not have any normal corms; therefore corn yields at 10 months may not represent the true potential yield of the treatments.

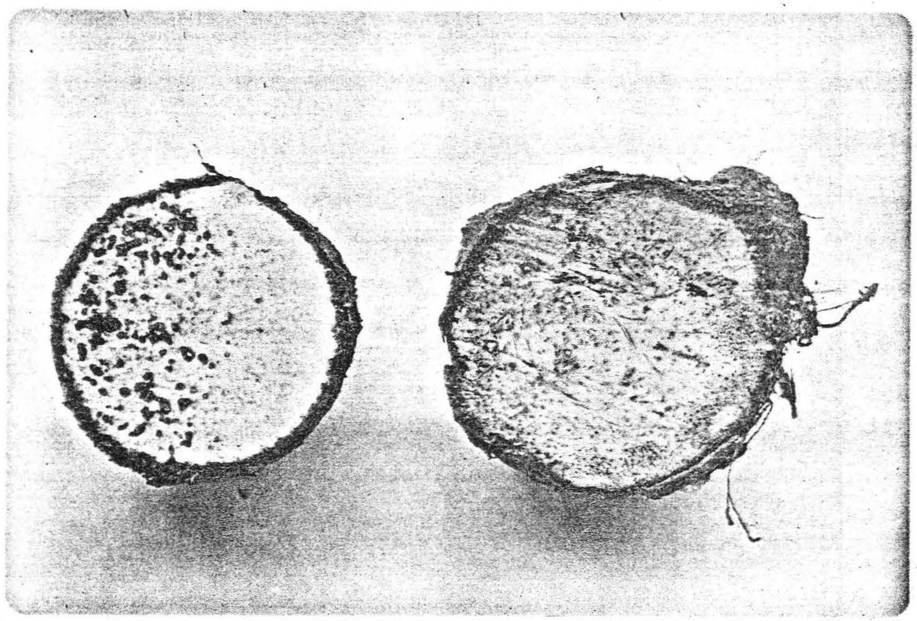
At the 12 month harvest, cormels were separated into marketable and non-marketable. Marketable cormels were those that can potentially be sold in the market raw and weigh over 32 grams each. All corms are potentially marketable. Diseased portions of the corms were sliced off each corm. Any corm that was less than half the original size after slicing was discarded. Those that were one half the original size were then multiplied by two and their weight added to the normal ones.

WATER REGIME EXPERIMENT

A water regime experiment was also conducted at Wailua Valley from July 1974 to July 1975. This experiment was designed to obtain information on the influence of this factor on corm and cormel yields as well as the quality (fermentation, flavor and color) of poi produced from these corms. Ease of harvesting was also evaluated.



a b



c d

Figure 4. Diseased and normal taro corms.

'Guava seed' or hard rot (a and c); soft rot (d) and normal corm(b).

Water treatments were as follows:

0. Continuous flooding (12 months)
2. Water drained 2 months before harvest
4. Water drained 4 months before harvest.

In order to minimize water seepage and for ease of water control, treatments were arranged systematically. That is, treatment 0 was closest to the main water inlet while treatment 4 was farthest away from the main water inlet. Each treatment consisted of six rows with 26 plants/row. Conventional flat culture without puddling was used. Hulis were planted 8 cm deep at a spacing of 100 x 30 cm.

Yield Data

The three inner rows from each of the treatments were harvested. The average weight of the non-marketable cormels was 37g.

Estimation of Labor Required at Harvest

A stop watch was used to note the time required by three men to pull out 24 hills of taro from three rows and removal of roots respectively. An average was then calculated and used to compute the time (man-hours/ha) on the basis of number of plants per hectare. The order of harvesting the three treatments was randomized.

Poi Preparation

Corms and cormels were randomly selected from each of the three treatments and boiled for about 1.5 hours. These were peeled after cooling and mashed in a 'cut-mix machine,' water being added at the ratio of 1.8 kg of water to 4.5 kg of peeled taro. Poi was then strained through a screen size 0.101 cm. Dry weights of corms and cormels and poi used to determine total solids were obtained by freeze drying for about 10 to 12 hours.

Taste Panel

The taste panel was conducted in the Food Science and Technology Department of the University of Hawaii. Nine people, randomly selected, all of whom had tasted poi before participated in the taste panel. Poi was made into a 'ready to eat poi' containing about 18% solids. Poi from each of the three treatments was given a code number but all the three kinds of poi were given to each taster at the same time, both in the morning and in the afternoon. The taste panel evaluated the poi on the basis of flavor and color.

POT STUDIES

Pot studies, designed to obtain information on morphological traits and corm plus cormel yields of taro as affected by temperature and light, were installed at Mauka campus of the University of Hawaii in 4.5 gallon plastic buckets lined with white plastic bags. Soil from the Waimanalo experimental farm (Waimanalo series) was used. Hulis of the Lehua taro variety were obtained from Wailua Valley, Kauai.

A 2 x 2 factorial experiment in a complete randomized block design was used with 8 replicates. Treatments were:

1. Planting depth - 5 and 10 cm
2. Source of huli - main and sucker hulis of uniform size.

   (Main huli = Planting material obtained from mother taro plant.
   Sucker huli = Planting material obtained from suckers)

Fertilizer rates were 2.64g N (as urea), 2.64g P (as treble superphosphate) and 2.09g K (as potassium chloride) per pot. All P and one-third each of N and K were thoroughly mixed with the soil at time of planting; the remaining N and K were applied one and two months after planting. Pots were grouped into three conditions with 8 replicates in each group (4x8=32 pots/group).

Group 1 - In greenhouse with 51% shade

Group 2 - Outside with 45% saran shade

Group 3 - Outside in full sunlight

A temperature recorder was installed in each group to provide a continuous record of air temperature. The crop was harvested at 7 months. Pots were completely flooded throughout the experimental period.

General Statistical Analysis of Data

Plant development, nutrient composition, corm and cormel yields and other morphological traits were evaluated by analysis of variance, regression and correlation techniques and Bayes Least-Significant Difference test (BLSD) using the University of Hawaii Computer Center.

Corm and cormel yields from the water regime experiment were not analyzed statistically because of inadequate replication. The taste panel results, consisting of a ranking of 1 to 7, for poi flavor and color were analyzed as a randomized complete block design. The nine tasters, randomly selected, were used as replicates.

RESULTS AND DISCUSSION

MAIN FIELD EXPERIMENT

Effect of Land Preparation, Spacing and Planting Depth on Sucker, Leaf and Area Development

Method of land preparation is an important management factor because of its influence on depth of root penetration into the soil, weed control, soil water retention or drainage and soil erosion. Plant spacing, on the other hand, exerts the mutual influence of competition for light, water and nutrients. It therefore sets a limit to the amount of plant growth possible. Problems involved in plant spacing are closely related to morphological characteristics such as leaf production, plant height or petiole length and erectness of leaves (Brenchley, 1919). Depth of planting has an influence on crop emergence.

1. Sucker Production

The results in Table 3 indicate that the highest number of suckers per plant was found with flat culture, but the difference was statistically significant (5% level) only at three months. The number of suckers obtained in the present study at three months was slightly less than those obtained in an earlier study (Ezumah, 1972) under flooding; whereas at nine months, the number of suckers in the present study was almost twice the number obtained in Ezumah's experiment (1972) at 10 months.

The 40 cm spacing produced the highest number of suckers per plant and the differences among spacings were all significantly different from each other. Depth of planting had no effect on the number of suckers produced. None of the interactions was significant except spacing x depth at seven months (Appendix Table 25).

Table 3. Effect of Land Preparation Method, Plant Spacing and Planting Depth on Production of Taro Leaves and Suckers Per Plant with Time

TREATMENT	Number of Leaves Per Plant				Number of Suckers Per Plant			
	MONTHS AFTER PLANTING							
	3	5	7	9	3	5	7	9
LAND PREPARATION								
Flat Culture	4.2	2.9	3.0	1.9b	4.6b	11.0	14.7	15.2
Ridge 13 cm High	4.2	2.7	3.0	2.1a	6.0a	11.0	13.6	14.2
Ridge 26 cm High	4.0	2.8	2.9	2.1a	6.0a	10.2	13.4	13.7
PLANT SPACING, CM								
20 x 100	3.9a	2.7b	2.9	2.1	4.9c	8.6c	10.6c	11.2c
30 x 100	4.2b	2.8ab	3.0	2.1	5.6b	10.7b	14.2b	13.9b
40 x 100	4.3b	2.9a	3.0	2.0	6.1a	12.9a	16.9a	17.9a
PLANTING DEPTH								
8 cm	4.1	2.7	2.9b	2.1	5.7	10.7	13.8	14.0
14 cm	4.2	2.8	3.0a	2.1	5.4	10.7	14.0	14.6

Means within land preparation, spacing and depth for the same age followed by different letters are significantly different (BLSD P = 0.05).

Generally, hulis with fairly well-developed sprouts or buds at time of planting have been observed to initiate more suckers that are fairly uniform. This early sprouting may be an important factor in determining final yields. This suggests that short term storage of hulis might be advantageous since taro has no dormancy period as does Irish potato.

2. Leaves and Leaf Area

Photosynthetic activity of a crop surface is influenced by (a) leaf area or foliage canopy, (b) nature of leaf display and (c) internal leaf quality. A crop surface, therefore, becomes rather complex (Loomis and Williams, 1963) because of differences in leaf size, shape, angle of display and response to light and wind.

a. Leaves

The effects of time, culture method and spacing on leaf number are shown in Figure 5. In general, number of leaves per plant decreased with age in all treatments. This is similar to results obtained with *Xanthosoma sp.* (Spence, 1970), and potatoes, *Solanum tuberosum* and *Ipomea batatas* (de Geus, 1973; Leopold *et al.* 1975). This decline in leaf number was associated with tuber development. Milthorpe (1967) has in fact suggested a translocation of food materials from the leaves and stems to the underground storage organs. Both reduction in shoot growth and leaf senescence at time of storage organ initiation has been a long known phenomenon (Heslop-Harrison, 1969). Events such as these are probably environmentally controlled and not merely due to chance.

Leaf number per plant increased as the spacing between plants was increased up to five months (Table 3). This may have been due to more light and/or higher plant temperatures at the wider spacing.

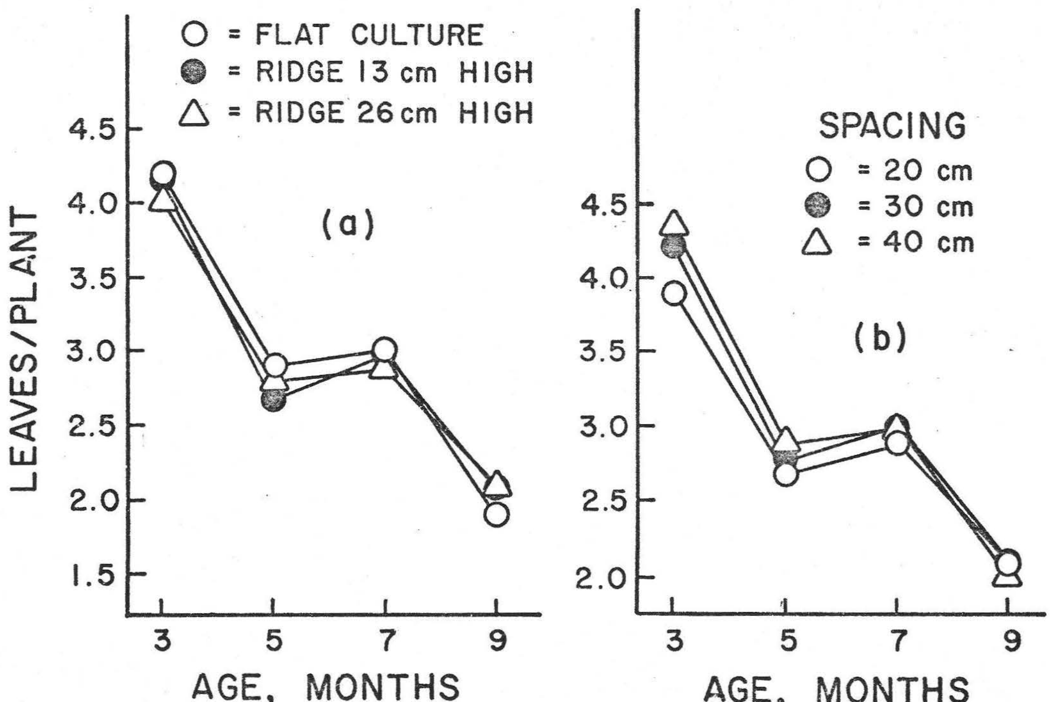


Figure 5.

Changes in production of taro leaves due to land preparation method and plant spacing.

Studies on rye grass (Mitchell, 1953) have indicated a decrease in number of days between appearance of successive leaves as light or temperature or both increased. Work on sweet potatoes (Hozyo, 1970; Sekioka, 1970) and Irish potatoes (de Geus, 1973) has also indicated high temperatures to be more favorable for vegetative growth than low temperatures. Since movement of air and light penetration would be more restricted under close than wide spacing, we might expect a lower temperature under close than wide plant spacing. This might therefore explain the slightly higher number of leaves under the wide than close spacing. Also, plants under the wide spacing may have more nutrients, particularly nitrogen, available because of the larger area/plant.

None of the interactions was statistically significant for leaf production (Appendix Table 25). Figure 6 shows the effects of land preparation x planting depth on leaf production per plant. None of the interactions was significant.

b. Leaf Area

Leaf area, as in the case of leaf number, decreased with crop age (Figure 7). Similar results have been reported for *Xanthosoma* (Spence, 1970), Irish potato (Milthorpe, 1967) and taro (Ezumah, 1972). This decrease may be due to senescence of the vegetative growth brought about by the development of storage organs (corms and cormels) and/or to decreased light and temperature caused by the mutual shading of leaves. Both leaf area and leaf number have been shown to decrease as light and temperature decreased (Carnegie Institute of Washington, 1936; Mitchell 1970). However, based on experimental results, Watson (1952) concluded that increased

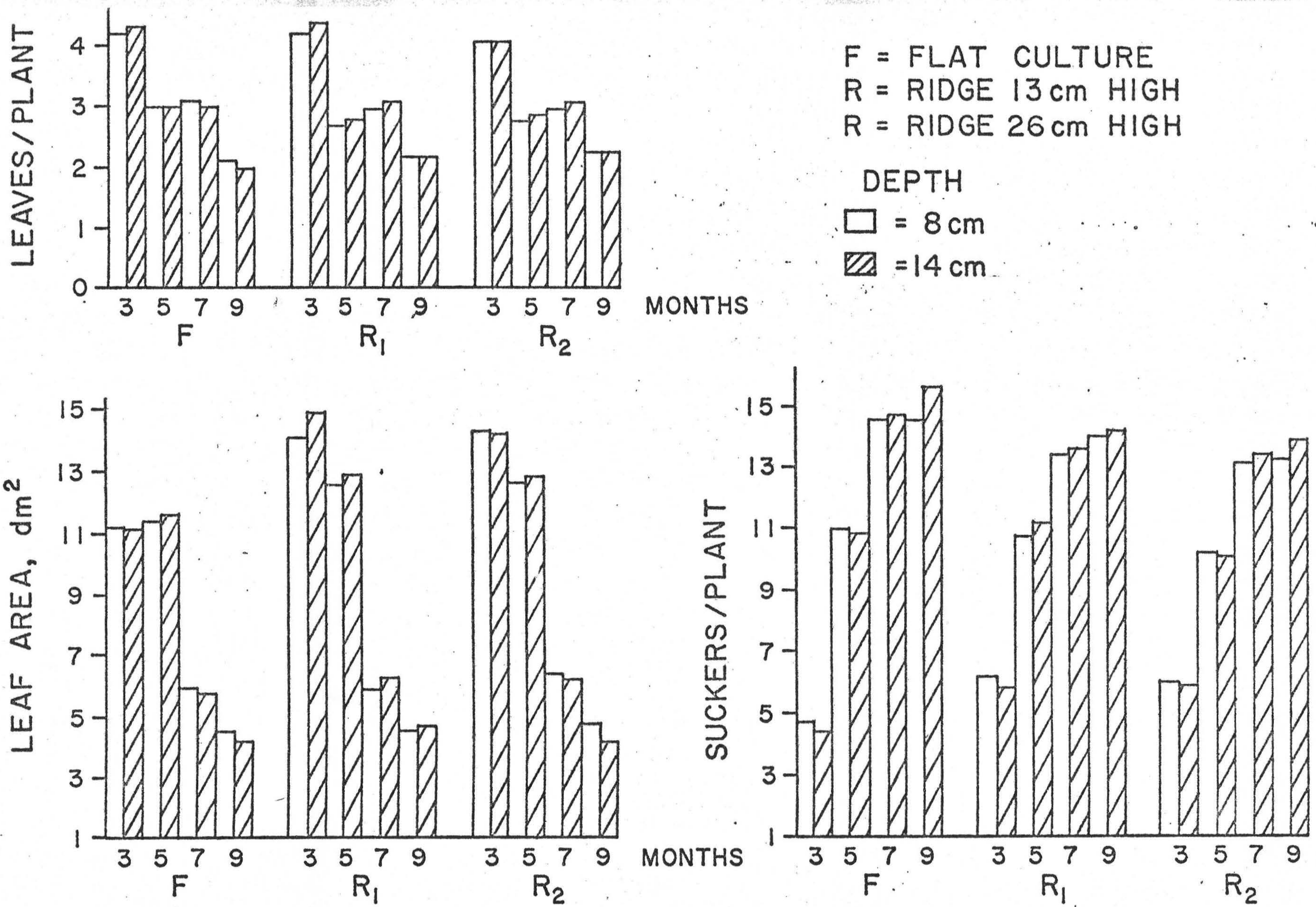


Figure 6. Effect of land preparation x plantig depth on taro leaf number, leaf area and sucker production with time.

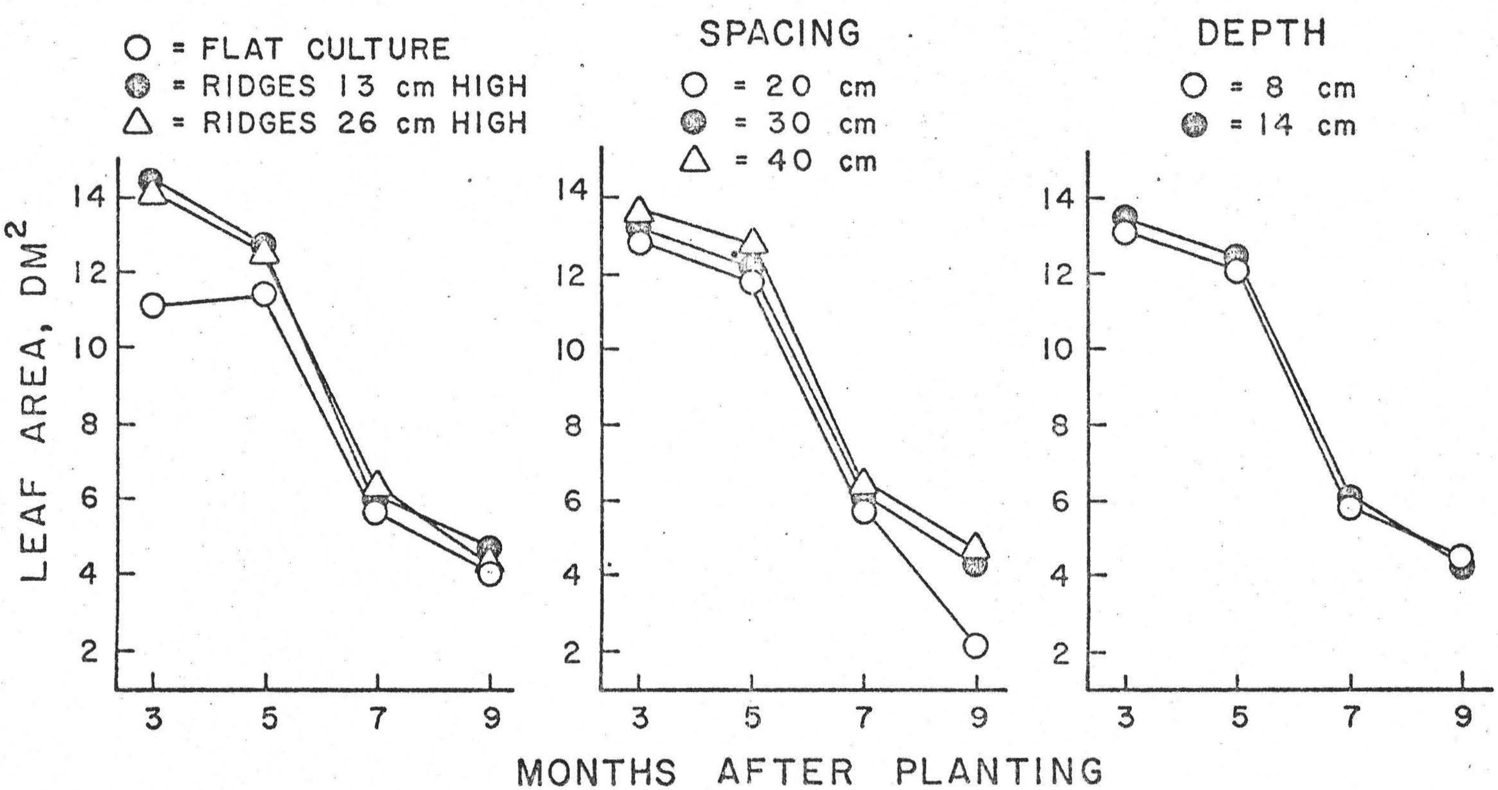


Figure 7. Effect of land preparation method, plant spacing and planting depth on mother-taro leaf area per plant with time.

illumination, continuous or temporary, decreases leaf area in open air; that temperature is also involved.

Ridging and increased spacing tended to increase leaf area per plant (Figure 7). Work on *Xanthosoma sp.* (Spence, 1970) has also shown increased leaf area per plant with increased plant spacing; while Donald (1963) has also cited work by Black on subterranean clover which showed fewer stems and leaves under normal than wide spacing. Roots will have more nutrients at wide than at close plant spacing. Therefore, increase in leaf area per plant at wide than at close spacing involves increasing leaf number and leaf size (Watson, 1952). The increase in leaf number with increase plant spacing was demonstrated in this study (Table 3). Cell division and expansion in the leaf may also be affected. This might suggest, among other things, an importance of (a) timing of fertilizer application (particularly nitrogen which has specifically been shown to increase leaf area (Spence, 1970) in *Xanthosoma sp.*), (b) mutual shading, (c) crop variety and (d) other crop management factors. A plant that is shaded by its neighbor has reduced photosynthetic activity. This results in less growth, smaller root system and less capacity of roots to explore the soil for nutrients and water.

In taro, all the nitrogen should be applied by the fifth month after planting in order to produce and maintain large leaf areas that are necessary for underground storage organ development.

The two planting depths had no significant influence on leaf area. Results of work (Haskins and Gorz, 1975) on sweetclover involving planting depth has also led the workers to conclude that influence of planting depth is more pronounced on the ability of the seedlings to emerge from the soil than on their performance after emergence.

The fact that leaf area per plant was greatest at three months after planting, the time at which the first measurements were taken, seemed to suggest that formation of taro corms could have started sometime before or immediately after three months. This suggestion is made because leaf areas and number of leaves in root crops have been shown (Humphries, 1967; Milthorpe, 1967; Spence, 1970; Leopold et al. 1975) to generally decrease or remain about constant immediately after storage organ initiation. The sharp decline in leaf area between five and seven months (Figure 7) after planting also might be indicative of the initiation of corm rot (Figure 4d) and leaf blight diseases caused by Phytophthora colocasiae Rac. The former disease is characterised by a general "firing" and reduction in top growth (Plucknett et al. 1970). This reduction in top growth was actually observed in the field.

3. Leaf Area Index, LAI

Attempts have been made to correlate rate of crop growth with amount of chlorophyll on a unit land area basis. However, photosynthetic activity per m^2 of land is not directly related to chlorophyll (Loomis and Williams, 1969) because leaf chlorophyll contents are generally well above levels required to sustain maximum rates of photosynthesis.

The relationship between leaf area and crop photosynthetic activity has received more acceptance since leaf area limits field photosynthetic rates until crop canopy closure has occurred. A plant that is shaded by its neighbors has a low photosynthetic activity. This results in less growth, smaller root system, hence less capacity of roots to explore the soil for nutrients and water. Watson's (1947) concept of leaf area index (LAI) (area subtended/ unit of ground) and its relationship to crop growth rate gm^{-2} day^{-1}) during the early stages of crop development has enhanced our understanding of crop photosynthesis in the field. The leaf area duration or its longevity is also important. Crop dry matter accumulation has been shown to be the product of photosynthetic rate per unit leaf area x leaf area x time. Therefore, with increasing leaf area and time up to a point, leaf number and size increase and light absorption; as well as rate of dry matter production increase.

Results in Figure 8 clearly show that MP-LAI decreased with crop age (see materials and methods for MP-LAI calculation). MP-LAI was consistently lower for flat culture than for ridge culture (Figure 8). The highest MP-LAI of 2.14 was obtained with the 13 cm ridge culture.

Leaf area indexes increased with decreased plant spacing. Similar results have been reported for maize (Allison, 1969; Winter et al, 1973), for tannia (Spence, 1970) and for taro (Ezumah, 1972). The highest MP-LAI of 2.52 was obtained at three months after planting with the closest spacing, 20 cm, whereas, the lowest MP-LAI of 0.25 was obtained at nine months with the widest plant spacing of 40 cm.

Deep planting tended to increase MP-LAI more than shallow planting (Figure 8). Provided N was moved into the soil, roots at the deep planting might have extracted more N than those at the

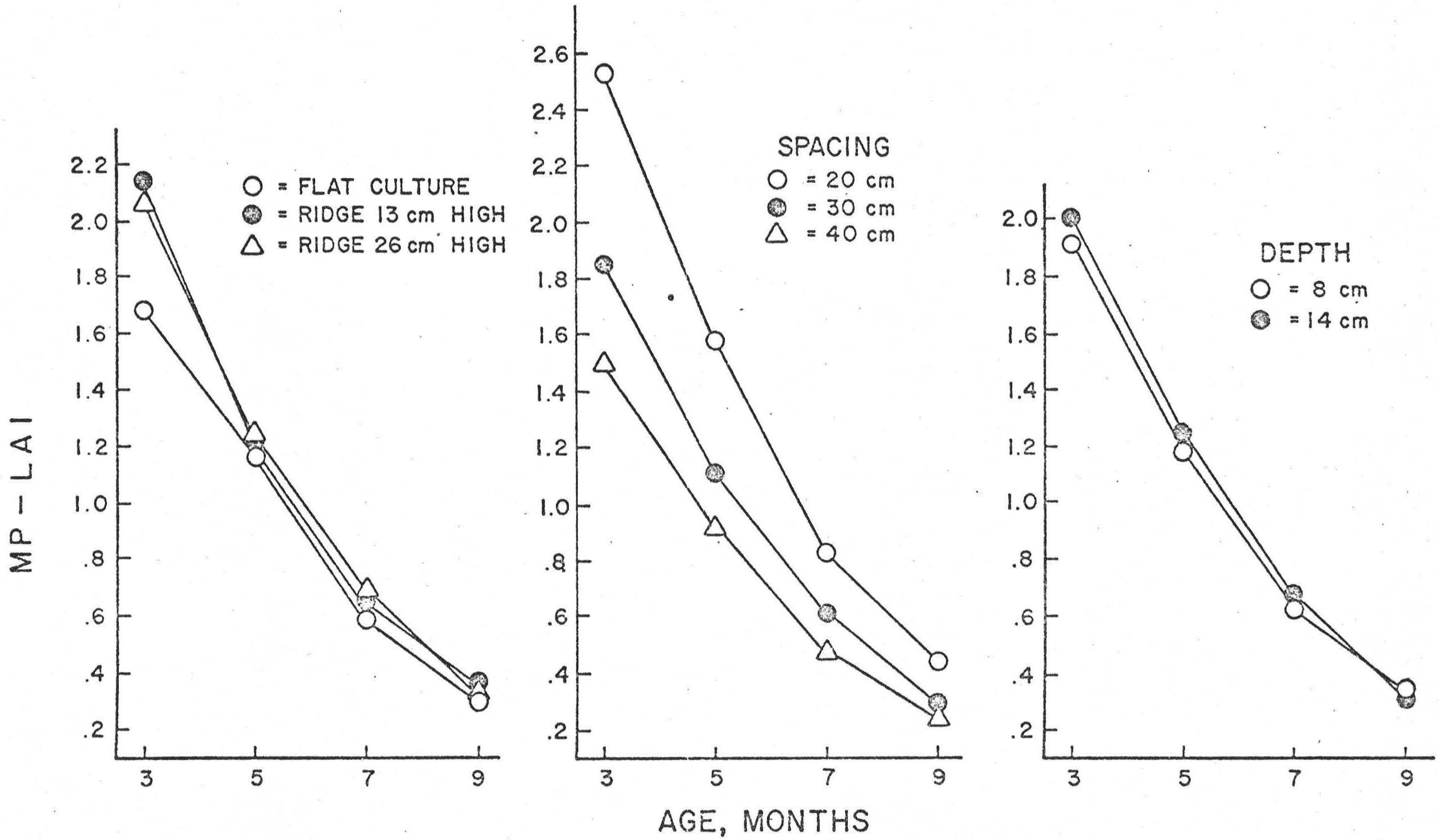


Figure 8. Changes in mother-plant leaf area indexes (MP-LAI) of taro with time as influenced by land preparation method, plant spacing and planting depth.

shallow planting. N has been reported (Watson, 1952; Murata, 1969) to increase LAI.

Mother-plant leaf area indexes obtained in this study were smaller than reported by Ezumah (1972) for taro. This might be due to a number of reasons. The major reason is that only leaves of the mother plant were used in LAI computation.

The finding that mother-plant leaf area indexes were already at a declining phase was probably because both leaf area and number of leaves per plant were also at a declining phase when this first measurement was taken. The present pot studies showed increased leaf area from two months after planting up to three months and then declined.

Effect of Land Preparation, Spacing and Planting Depth on Total Solids, Specific Gravity, Lateral and Vertical Growth of Corms and Cormels, Hill Circumference and Vertical Force

1. Total Solids and Specific Gravity

Measurement of specific gravity is commonly used as an internal quality index in potatoes and taro. Specific gravity is closely related to starch content, total solids and mealiness of corms and cormels. For instance, corms and cormels with high specific gravity give a mealy product and more chips in Irish potatoes than those of low specific gravity (Whittenberger, 1952), whereas in taro, there seems to be a positive correlation between specific gravity of corms and cormels and poi recovery.

The dry weights (total solids) of corms and cormels increased with age and were lower for flat than for ridge culture (Table 4). This difference in total solids between flat and ridge culture was

Table 4. Influence of Land Preparation, Plant Spacing and Planting Depth on Some Taro Characteristics

CHARACTER	Months after planting	LAND PREPARATION Flat culture	Ridge Height CM 13	26	PLANT SPACING, CM 20	30	40	PLANTING DEPTH 8	14
Solids in corms & cormels (g/100g)	10	37.74	38.46	40.10	38.98	38.73	38.59	38.82	38.71
Solids in corms & cormels (g/100g)	12	39.12b	40.68a	41.43a	40.31	40.18	40.75	40.31	40.51
Corm specific gravity	10	1.05	1.06	1.07	1.06	1.06	1.06	1.06	1.06
Cormel specific gravity	10	1.12	1.13	1.14	1.12	1.14	1.13	1.14	1.12
Corm & cormel lateral growth, cm	10	23.38	24.08	23.77	22.85	23.57	24.81	23.04b	24.44a
Corm vertical growth, cm	10	13.59	14.62	14.28	14.20	14.14	15.15	13.92	14.40
Circumference/hill, cm	10	78.54	82.51	84.43	70.73c	83.43b	91.31a	81.61	82.05
Rotten corms, %	10	69.44	83.56	80.00	71.67	86.50	74.83	73.11b	82.22a
Vertical force to pull taro, hill, kg	10	45.2		48.2	44.8		48.5	45.7	47.6

Means in the same row and without or followed by the same letter are not significantly different (BLSD P = 0.05).

significant (5% level) at 12 months. The differences in total solids due to plant spacing and planting depth were non-significant. However, the values obtained in this study were higher than those reported by Ezumah (1972) but slightly lower than those reported by de la Pena (1967) under paddy culture. A number of workers (Milthorpe, 1967; Humphries, 1967, Spence, 1970; Sekioka, 1970) have used the concept of source-sink to explain this phenomenon in which as solids or photosynthates in the vegetative parts decrease, those in the underground storage organs or grains steadily increase. These workers have presented considerable evidence that suggests that an increased demand for assimilates by the sinks might increase photosynthetic rates. Much of this evidence stems from manipulating the sinks, for instance, by removal of grains (Allison, 1969), or by increasing the number of cormels thereby increasing net assimilation rate (rate of dry matter increase per unit area of leaf) and hence yield.

Also, it might be that photosynthetic materials in the leaves move at the expense of the leaves to the underground storage organs or that newly photosynthates move preferentially to the underground storage organs. The involvement of photoperiod, light, temperature and hormones in the development of tubers has been implicated (Leopold and Kriedemann, 1975).

Results in Table 4 indicate slightly higher specific gravities in cormels than in corms. Also, the flat culture regime appeared to depress specific gravities when compared with the ridge culture. Both plant spacing and planting depth produced comparable specific gravities. Similar findings have been reported (Bowers et al. 1964; de la Pena, 1967; Ezumah, 1972). Specific gravity values reported for corms in this study are similar to those reported for Sebago potatoes (Lucas, 1968). Although K was not a variable in this experiment, Cummings and Wilcox (1968) have cited results of a number of workers which indicate that when K_2SO_4 and KCl are applied in a band at equal rates of K potato tubers of higher starch content and specific gravity were produced with K_2SO_4. This suggests that K_2SO_4 may be preferable to KCl for taro (as the case in this study).

2. Maximum Corm and Cormel Lateral Growth and Corm Vertical Growth

In relation to mechanization, estimations of lateral growth across the row and vertical growth of corms become important in determining both the size of auger and the depth to which it should be placed during harvesting in order to prevent corm and cormel damage.

Differences in lateral corm and cormel growth due to method of land preparation were nonsignificant (Table 4 and Figure 9d).

Lateral corm and cormel growth per hill (hill = all plants that have arisen from original huli) increased with plant spacing (Table 4 and Figure 9e). This was expected because of increased sucker production per hill with increased spacing. The fact that differences in sucker production among the three spacings were significant (Table 3) but not those of corm and cormel growth, was probably because (a) only two plants were sampled per sub-subplot for corm and cormel growth compared to 10 plants for suckers, and (b) measurements for lateral growth were only taken across the row while cormels are distributed haphazardly around the corm.

The significant difference (Table 4) in lateral corm and cormel growth found between the two planting depths suggests that observations made at harvest which indicated that cormels from the deep planting

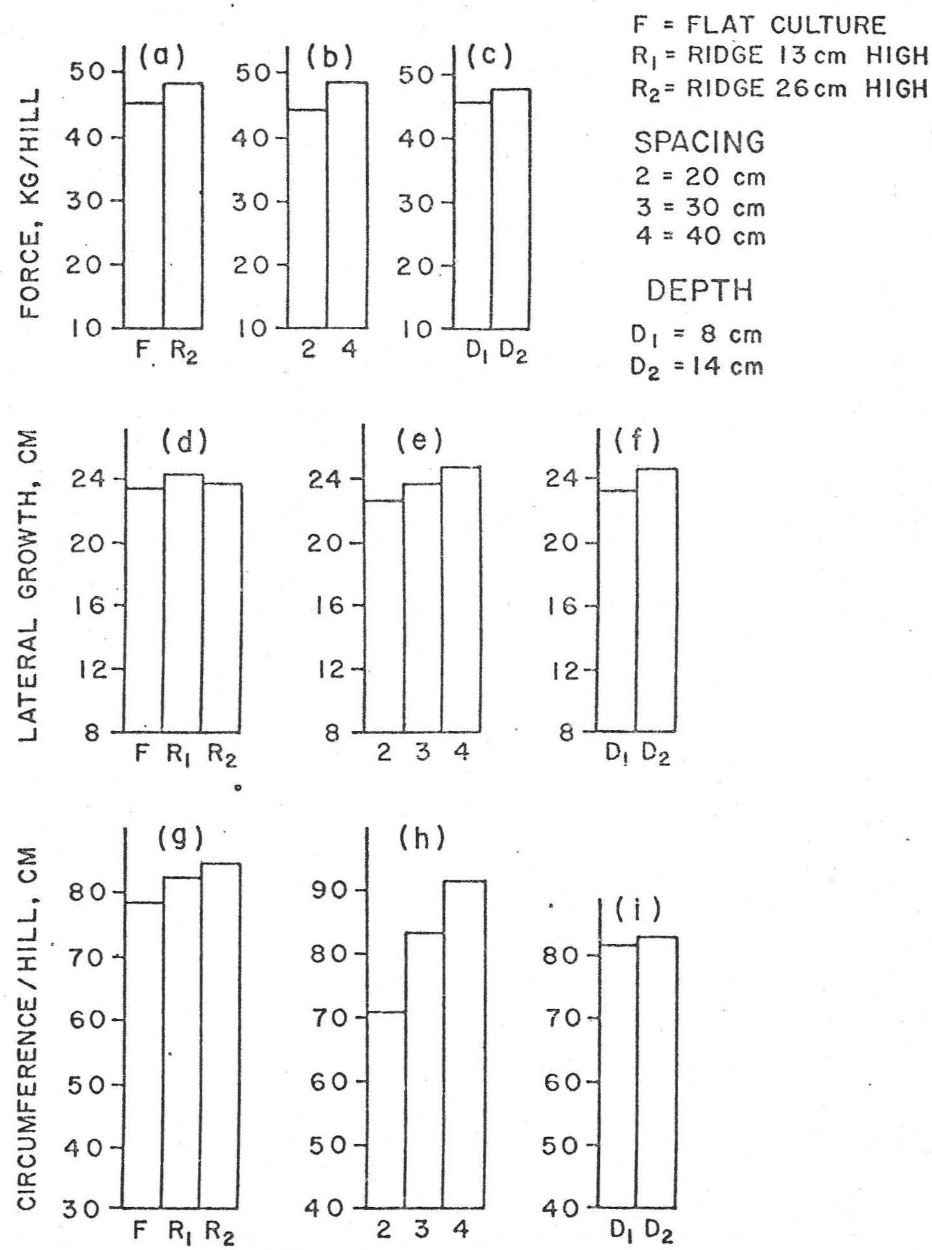


Figure 9. Effect of land preparation method, plant spacing and depth of planting on vertical force to lift a taro hill (a,b,c), maximum lateral growth of corms and cormels (d,e,f) and circumference of suckers per hill (g,h,i) at 10 months.

tended to bend away more from the corm than did those from shallow planting (Figure 10).

The finding that vertical growth of corms from both deep and shallow planting (Table 4) was about equal may be related to either the physiology of corm formation or to experimental errors, since when corms were partly rotten, the depth had to be estimated from remains of the base of the corm. In addition, only two plants were sampled per sub-subplot.

3. Circumference of Hills

According to Table 4 and Figure 9g, circumference of hills tended to increase with ridging. Flat culture had an average cùrcumference of 78.54 cm compared to 84.43 cm per hill for the 26 cm ridge culture. However the differences were not significant and this might be expected since the effect of treatments on sucker production was also not significant except at three months (Table 3). Increased plant spacing significantly increased hill circumference (Table 4 and Figure 9h) due t to the greater number of suckers/hill as spacing increased. Planting depth appeared to have no effect on hill circumference.

4. Vertical Force per Hill

Harvesting taro requires long hours of stooping and therefore can be back-aching. Pulling the corms out of the ground requires prying with a sharp, heavy iron bar. Therefore, measurements were made of the force required to pull a taro hill out of the ground.

According to results in Table 4 and Figure 9a, the vertical force was less in flat culture than in ridge culture. This was unexpected, since in general it was easier pulling taro grown on ridge than grown in flat culture during harvesting. Perhaps this was due either to

a b c d

Figure 10. Effect of planting depth on shape of taro corms and cormels. 14 cm planting depth (a and d); 8 cm planting depth (b and c).

experimental errors or to the accuracy of the method used to measure vertical force. However, none of the differences due to land preparation were significant.

In most cases plants could be pulled by hand from the ridges without prying with an iron bar or one's heel during harvesting, while it was almost impossible to pull plants without prying in flat culture. This is because soil in the ridges was less compact and the absence of soil on the two sides of the furrows reduced the energy required to lift corms and cormels.

The increase in vertical force required to pull a hill of taro with increased plant spacing was expected by virtue of the higher number of suckers, and hence more roots under the wider spacing (Table 4 and Figure 9b). The insignificant difference between the 20 and 40 cm plant spacings was perhaps due to inter-hill root overlap with the close spacing.

Increased depth of planting also increased the amount of force required to pull a hill of taro and was expected because corms and roots extended further into the soil. Roots may have also been more extensive at the deeper depth, but this was not tested experimentally.

These data have demonstrated that harvesting of taro requires considerable energy and may explain why taro production in Hawaii is not attractive to potential young farmers.

Effect of Land Preparation, Spacing and Planting Depth on Nutrient Composition of Corms and Cormels

Corms and cormels under flat culture tended to accumulate more nutrients than those from ridged culture (Table 5). Perhaps this might be due to the more extensive root system that was observed under flat

Table 5. Influence of Land Preparation, Plant Spacing and Planting Depth on Nutrient and Protein Content of Taro Corms Plus Cormels at 10 Months

TREATMENT	N %	P	K	Mg	Ca	Na	Cl	Protein[1/]
				DRY	WEIGHTS[2/]			
LAND PREPARATION								
Flat Culture	0.65	0.11	0.27	0.07	0.06	0.11	0.15	4.08
Ridge 13 cm High	0.54	0.10	0.28	0.06	0.06	0.10	0.12	3.35
Ridge 26 cm High	0.50	0.10	0.25	0.06	0.05	0.09	0.11	3.11
PLANT SPACING, CM								
20 x 100	0.56	0.10	0.25	0.07	0.06	0.10	0.13	3.48
30 x 100	0.57	0.10	0.27	0.06	0.06	0.10	0.12	3.54
40 x 100	0.57	0.10	0.27	0.07	0.06	0.09	0.13	3.54
PLANTING DEPTH, CM								
8	0.55	0.10	0.26	0.06	0.06	0.10	0.13	3.44
14	0.57	0.11	0.28	0.07	0.06	0.10	0.13	3.59

[1/] Protein = N x 6.25; [2/] Air dry weights.

culture than under ridged cultures during harvesting. This may also be a dilution effect since total corm yields were less with flat culture than with the two ridged cultures at both harvest dates (Table 6).

These findings were somewhat contrary to those of Ezumah, (1972) who reported that nutrients were consistently higher under ridged than flat culture. However, differences in nutrient content among treatments were not significant in the present study. This is also reflected in corm and cormel total solids, (Table 4) and total corm yields for land preparation and planting depth (Table 6). The lack of significant differences in nutrient composition between treatments was not surprising since fertilizer rates (NPK) were uniform. Concentration of P in Ezumah's (1972) study was 0.18 percent under flat culture compared to 0.113 in the present study. The higher value obtained in Ezumah's study may be due to (a) higher rate of P (600 versus 500 kg/ha) application, (b) only corms were analysed and (c) core samples rather than an entire representative sample (see method used in the present study) were taken for chemical analysis. Concentrations of N and protein were higher under flat culture than ridged culture (Table 5).

Nutrient composition of corms plus cormels was quite similar for the two planting depths. This suggests that roots had similar access to nutrients and extracted them to the same degree. Another interesting point is that roots appeared to be produced fairly uniformly on the vertical surface of both corms and cormels; thus roots were exposed to a larger surface area.

Alkaline-forming elements (Na,K,Ca,Mg) exceed acid-forming (S, P, Cl) in both taro corms and cormels and poi; and Jones _et al._ data are cited by Derstine and Rada (1952) as implicating that a diet that

Table 6. Influence of Land Preparation Method and Planting Depth on Taro Yields (metric ton/ha) at 10 and 12 Months*

YIELD TRAIT	LAND PREPARATION METHOD			PLANTING DEPTH	
	Flat Culture	Ridge Height, cm 13	Ridge Height, cm 26	8 cm	14 cm
10 MONTHS					
Corms	13.79	17.26	17.86	16.41	15.49
Rotton corms, %	69.00	83.00	80.00	73.00b	82.00a
Cormels	27.68	30.70	26.19	28.48	27.91
Total yield	41.47	47.96	44.05	44.89	43.39
12 MONTHS					
Corms	16.92	19.27	17.91	18.23	17.86
Marketable cormels	35.69	40.18	40.11	37.29	40.03
Total cormels	38.52	43.03	42.62	40.41	42.37
Corms + marketable cormels	52.61	59.45	58.02	55.52	57.89
Total yield	55.44	62.40	60.53	58.64	60.23

*Means in the same row and without or followed by the same letter are not significantly different at the 5% level. Except for cormels, 10 month yield data were not evaluated statistically due to some rotten corms in some plots.

provides proper acid-base balance with an alkaline excess results in good teeth.

Effect of Land Preparation, Spacing and Planting Depth on Corm and Cormel Yields

Land Preparation

Method of land preparation is a management practice that affects the performance of a crop due to its influence on drainage or soil water retention, weed control and capacity of roots to explore the soil for nutrients and water.

The 10 month corm and total yields (corm + cormels) shown in Table 6 should be treated with caution since their calculations were based only on normal corms and in some plots all corms were either partly or completely rotten. The results shown in Table 6 show that ridging tended to increase yields more than conventional flat culture at both harvest dates. Highest total yields of 47.96 and 62.40 ton/ha at 10 and 12 months respectively were obtained under the 13 cm ridge height culture; whereas lowest total yields of 41.47 and 55.44 ton/ha at 10 and 12 months were obtained under flat culture. The results in Table 6 further show that most of the cormels would be marketable (all cormels that weigh over 32.0g and can potentially be sold raw in the market) when taro is harvested at 12 months. However, none of the yields was significantly different among the three land preparation methods.

Posnette (1945) reported higher yields for maize, yams, sweet potatoes and cotton grown on large ridges than on small ones or flat culture both under wet and dryland areas. However Okigbo (cited by Enyi, 1967) found no significant response of cassava to ridge or flat culture. Similar results were reported for taro by Ezumah (1972). Work on beans (Cartee and Hanks, 1974) has also indicated a 21% greater average yield from ridge culture than from the control.

Mounds were reported (Kimber, 1970) to result in higher yields of sweet potatoes than ridges of the same size. The superiority of mounds over ridges was attributed to more efficient soil aeration and reduced tendency for soil compaction. The same reasons might explain the slightly higher yields with ridges than with flat culture in the present study. Interestingly, the number of cormels per hectare at the 12 month harvest were slightly higher for the flat than for the ridge culture even though yields on the ridged plots were higher. This suggests that cormels from the flat culture plots were generally smaller in size than those of the ridges and/or had less solids than those of the ridged cultures (Table 4).

The superiority of ridges over flat culture in terms of solids in corms and cormels at 12 months, the slightly higher corm and cormel specific gravity (Table 4), yield (Table 6) and ease of harvesting, are all encouraging. Ease of machine trafficability under ridged and flat cultures has yet to be evaluated quantitatively under flooded conditions. However, if harvesting is to be performed under partly or completely dry conditions, it would be both easier and quicker to drain water from ridged than flat culture because of the presence of furrows and better drainage conditions under ridged culture. Also, well contoured ridges would help control soil erosion.

Whether the existing farmers in Hawaii would be willing to adopt ridging in the commercial production of taro is debatable, particularly since this practice appears to require more labor initially than the conventional flat culture. However, it by-passes the conventional practice of puddling the soil as a means of breaking down soil aggregates. Changing peoples habits may be very difficult and most farmers may be content to accept reduced yields rather than adopt a practice that is relatively new to them.

Table 6 also shows increased yields with crop age which is due to the fact that corms and cormels particularly, were still increasing in size. This is in general agreement with earlier work by de la Pena (1967) and Ezumah (1972). There is no obvious explanation for the slightly higher percentage of rotten corms under ridged than flat culture in Table 6.

Plant Spacing

The main objective of any planting program is to obtain a plant population that will effectively utilize all solar radiation as quickly as possible. Optimum plant spacing is influenced by many factors but sunlight, water and nutrients are probably the most important.

The results in Figures 11-14 show the influence of three plant populations, 25,000, 33,333, 50,000 (100 x 40, 100 x 30, 100 x 20) on corm and cormel yields at 10 and 12 months. In general, yield increased both with age and planting density. Similar yield increases with increasing planting density were reported for yams (Cruzado et al. 1964; Gooding and Hoad, 1967; Enyi, 1970), Irish potatoes (Chapman, 1965) and taro (Ezumah, 1972).

Corm, cormel and total yields at 10 months increased with increasing planting density to the maximum of 50,000 plants/ha (Figures 11-14). The increase in yields with increased planting density was also

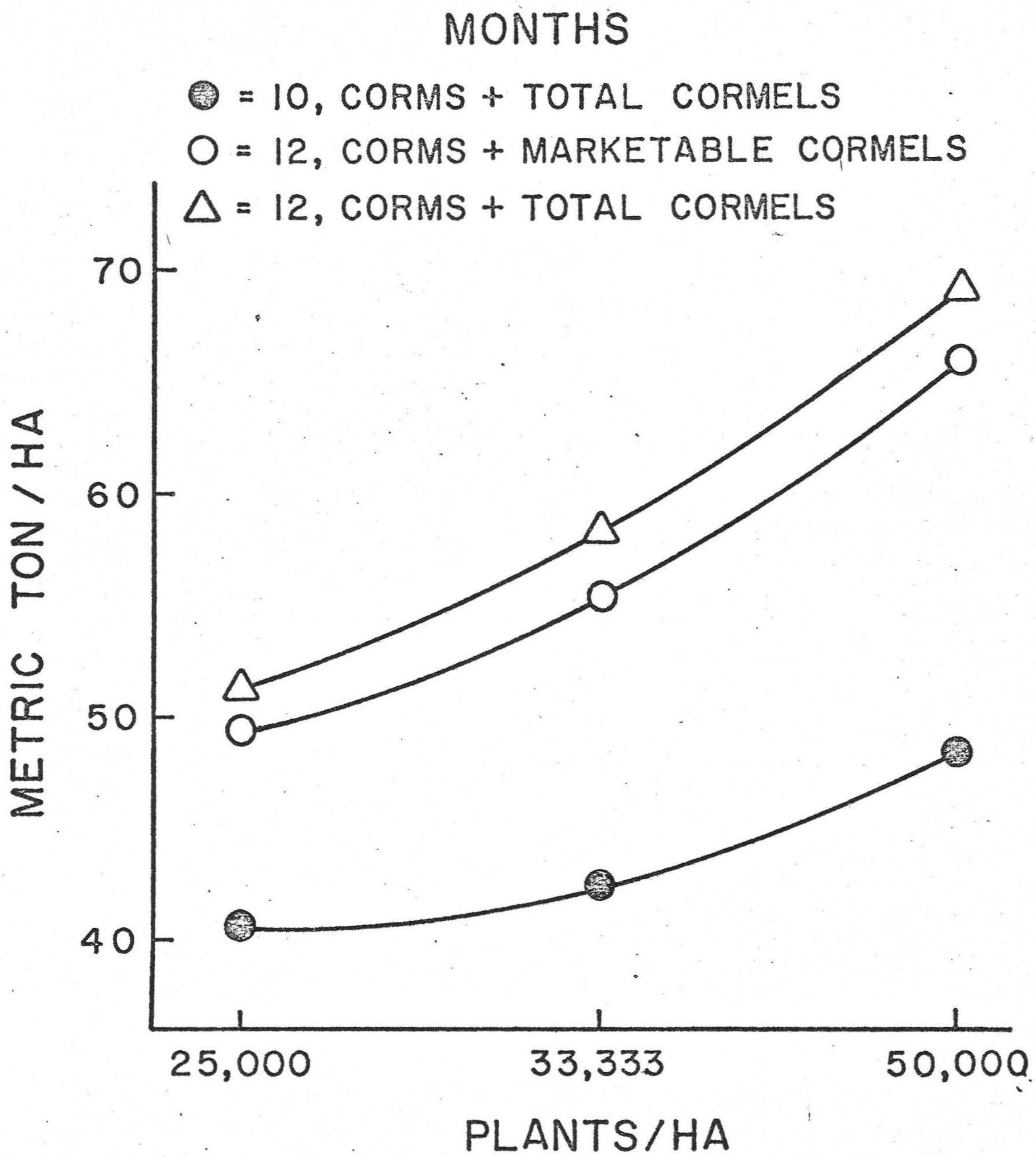


Figure 11. Effect of planting density on taro corm and cormel yields.

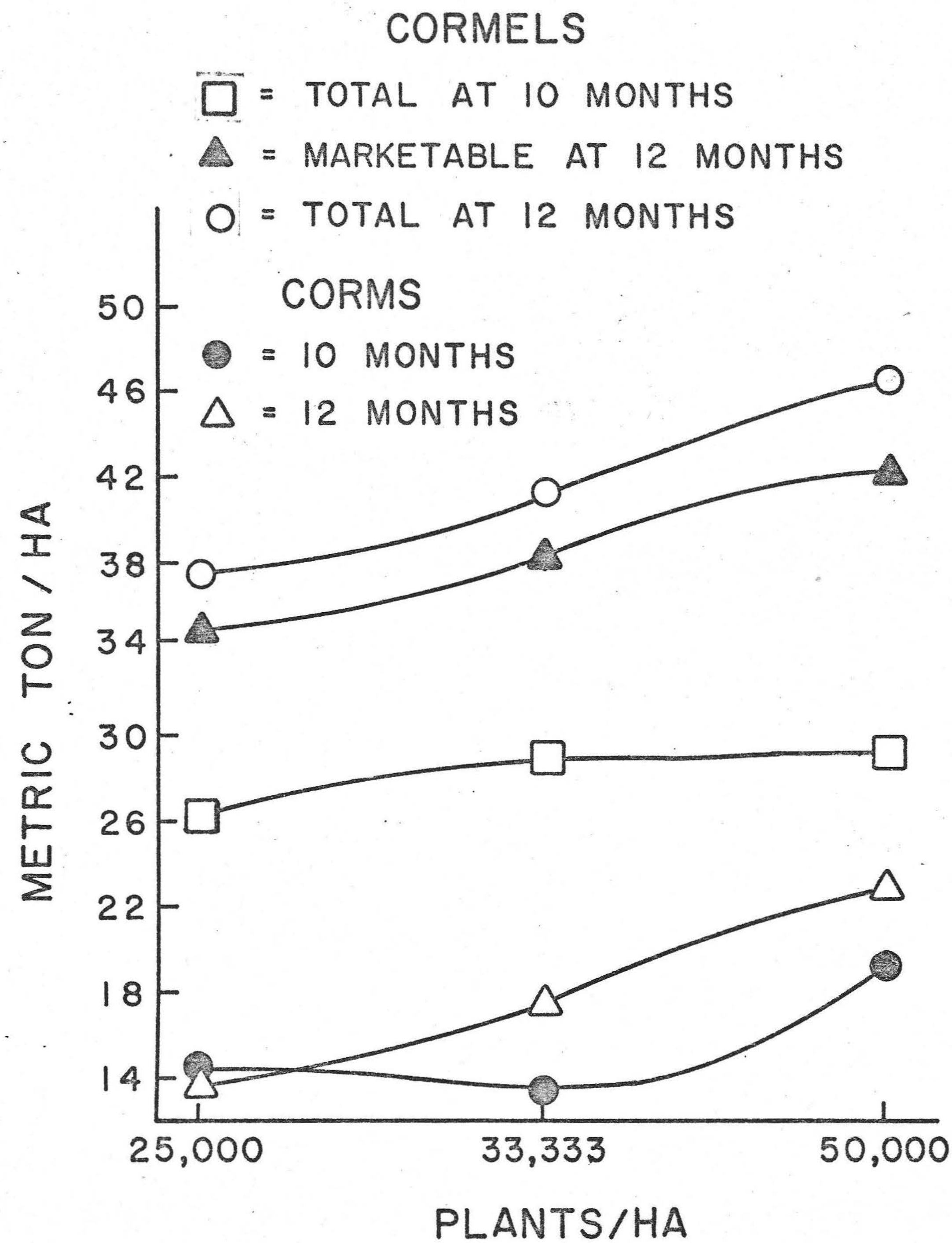


Figure 12. Effect of plant population on taro corm and cormel yields at 10 and 12 months.

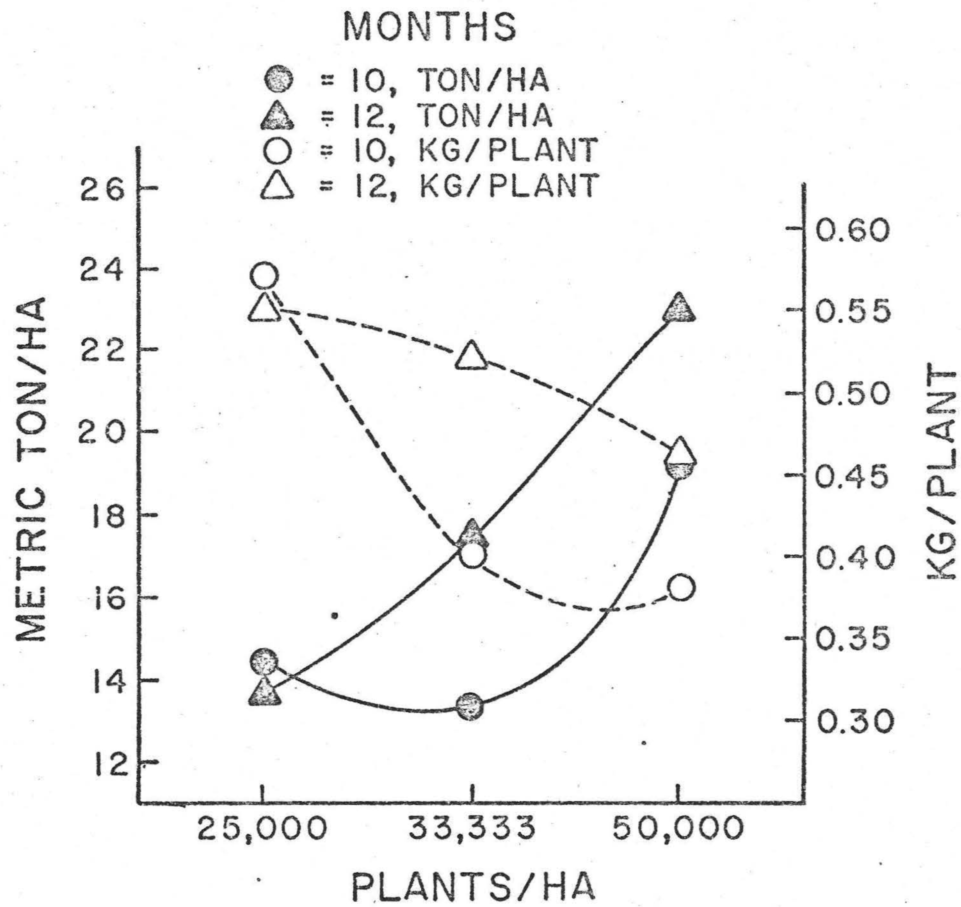


Figure 13. Effect of plant population on taro corm yield at 10 and 12 months.

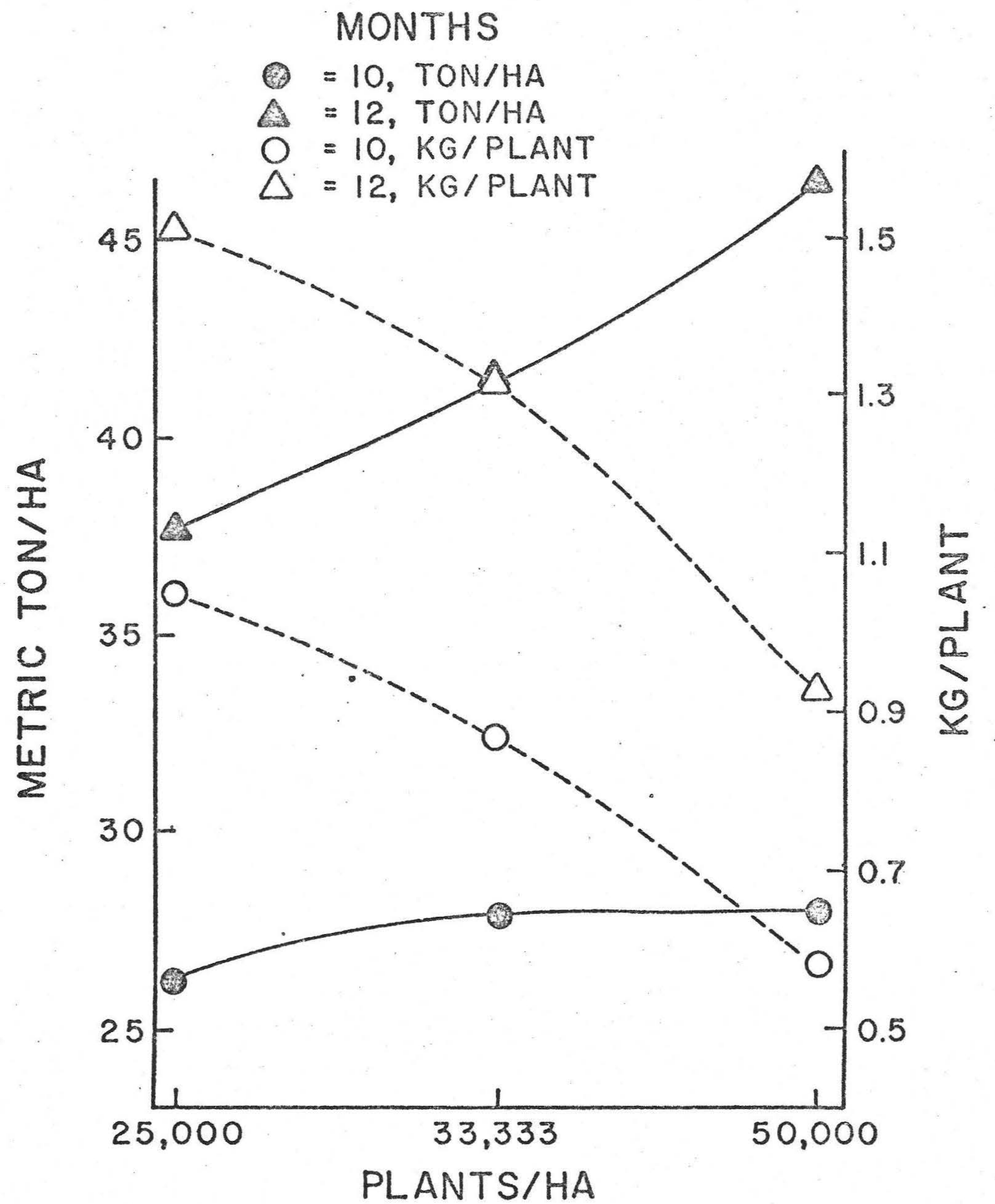


Figure 14. Effect of planting density on taro cormel yield at 10 and 12 months.

highly significant (1% level) at the 12 month harvest (Appendix Table 28). The yield differences among plant populations for corms, corms + marketable cormels and total yields (corms + total cormels) were significantly different from each other. In relation to marketable and total cormels, only the yield at 50,000 plants/ha was significantly higher than the two lower planting densities; the yield difference between 33,333 and 25,000 plant/ha was not significant.

Information indicating that yields (grain, stover or tubers) increase as planting densities increase is abundant in the literature. This increase is attributed to more plants per unit area of land which intercept the incident radiation from the sun and thereby enhances the process of photosynthesis on a unit area basis. This points to the significance of leaf area and leaf area index (LAI) concepts since leaves are the photosynthetic organs. At low crop densities, newly emerged seedlings do not compete for light and the crop growth rate is therefore dependent both on the number of plants and the initial leaf area per plant. Therefore, by increasing the number of plants per unit of land, the period required to reach optimum LAI can be shortened. However, an excessive number of plants per unit area can ultimately cause overcrowding which may result in reduced economic yield.

The effect of plant population on the number of marketable cormels at 12 months was significant (Appendix Table 29). Studies (Kimber, 1970) on sweet potatoes showed reduced marketable tuber yields per plant but increased yields per hectare at close spacing in both mounds and ridged cultures. This is to be expected because of greater competition on both an inter and intra-plant basis. This might explain the insignificant difference in marketable cormel yield between the 25,000 and 33,333 plants/ha because the larger size cormels at the 25,000 plants/ha was enough to off-set the greater number of cormels at the 33,333 plant/ha.

Maximum yield was not reached in the present study (Figure 11) but equally interesting was the significantly higher marketable cormel yield at the highest planting density than at the lower densities. Similar findings have been reported (Kimber, 1970) for sweet potatoes.

Results in Table 7 show increased yields (kg/plant) with increased plant spacing. Yield of cormels at 10 months and marketable cormels at 12 months (Table 7) were highly significant (1% level) due to plant spacing.

In Hawaii, the spacing commonly used by farmers (Plucknett et al. 1973) is 60 x 40 cm (36,000 plant/ha). While some farmers obtain yields between 35-45 ton/ha, the average yield for the state in 1969 was 22.4 ton/ha. Therefore, based on the results of the present study, farmers can potentially expect higher yields at a closer plant spacing than presently used.

A great deal of attention has been given to closer row spacings of agronomic crops as a means of increasing yields. Theoretically, when soil fertility and plant population are adequate, the factors limiting growth would be light, CO_2 supply and other factors related to leaf area and photosynthetic capacity (Winter and Ohlrogge, 1973). This introduces the concept of mutual shading of leaves. That is, as growth of a plant continues, there comes a time when increased leaf size results in shading of lower leaves until a point is reached where any further increase in leaf surface does not result in further increase in capture of radiant energy. Mutual shading reduces crop yield directly by

Table 7. Influence of Land Preparation Method, Plant Spacing and Planting Depth on Taro Yields (kg/plant) and Number of Marketable Cormels at 10 and 12 Months

YIELD TRAIT	LAND PREPARATION METHOD Flat Culture	Ridge Height, cm 13	Ridge Height, cm 26	PLANT SPACING, CM 20	30	40	DEPTH, CM 8	14
			10 MONTHS					
Corms	0.39	0.47	0.51	0.38	0.40	0.57	0.44	0.46
Cormels	0.82	0.91	0.78	0.58c	0.87b	1.05a	0.84	0.83
Total Yield	1.21	1.38	1.29	0.96	1.27	1.62	1.28	1.29
			12 MONTHS					
Corms	0.47	0.55	0.51	0.46	0.52	0.55	0.51	0.51
Marketable cormels	1.05	1.23	1.16	0.86c	1.15b	1.43a	1.12	1.18
Total Yield	1.52	1.78	1.67	1.32	1.67	1.98	1.63	1.69
Number marketable cormels/ha	324721	309860	309490	374444a	300182b	267778c	299968	328301

Means in the same row and without or followed by the same letter are not significantly different (BLSD P = 0.05). Except for cormels, 10 month yield data were not evaluated statistically due to some rotten corms in some plots.

reducing light that might be available for photosynthesis (Wilson and Teare, 1972).

Land Preparation X Plant Spacing Interaction

No significant interactions between land preparation and plant spacing were obtained at either 10 or 12 months (Figures 15-17). This suggests that if any real interaction between method of land preparation and spacing existed, the experiment was not sensitive enough to detect it.

Planting Depth

The effects of planting depth on taro yields are shown in Tables 6 and 7. Yields at the shallow and deep planting depths were not significantly different for both corms and cormels at 10 and 12 months.

Though the literature contains much information on depth of planting for seed crops, there is little information of this kind for taro or cassava. In relation to sugarcane and seed crops, deep planting delays emergence and increases seed mortality (Humbert, 1968; Scrifres and Brock, 1972; Dawson and Burns, 1972; Hakanson _et_ _al_. 1972; Hurdus, 1975). However, there is a basic difference between seed crops and taro; while the former are completely covered with soil in the case of the latter, only a part of the planting material is covered with the soil. Therefore, the only effects planting depth may have on taro would be those related to water, aeration and nutrient status rather than to light, for example.

Light and soil temperature are important factors that affect the emergence and subsequent performance of seeds or seed-setts. An undesirable effect of deep planting is also on delay of crop emergence

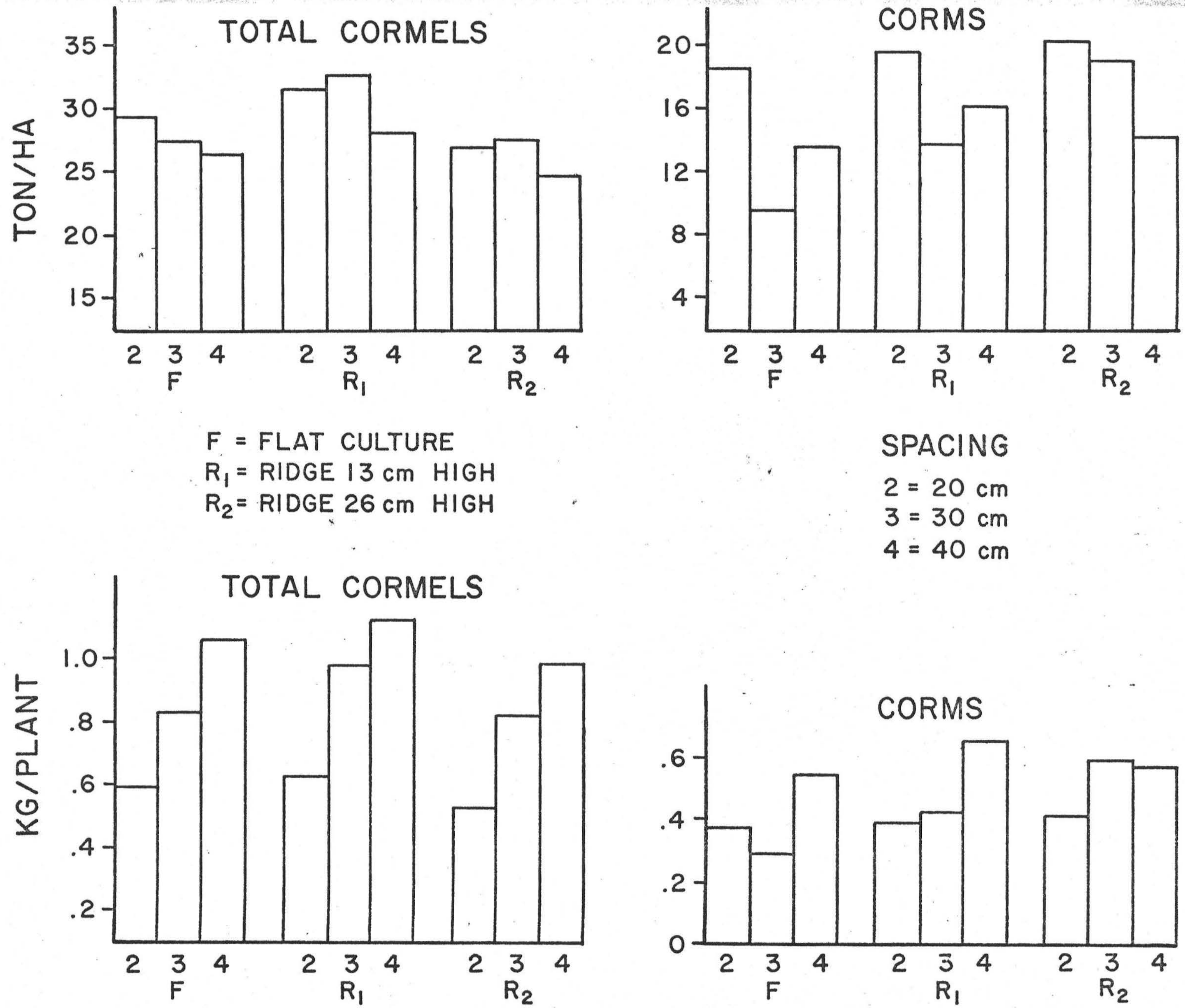


Figure 15. Effect of land preparation x plant spacing on taro yield at 10 months.

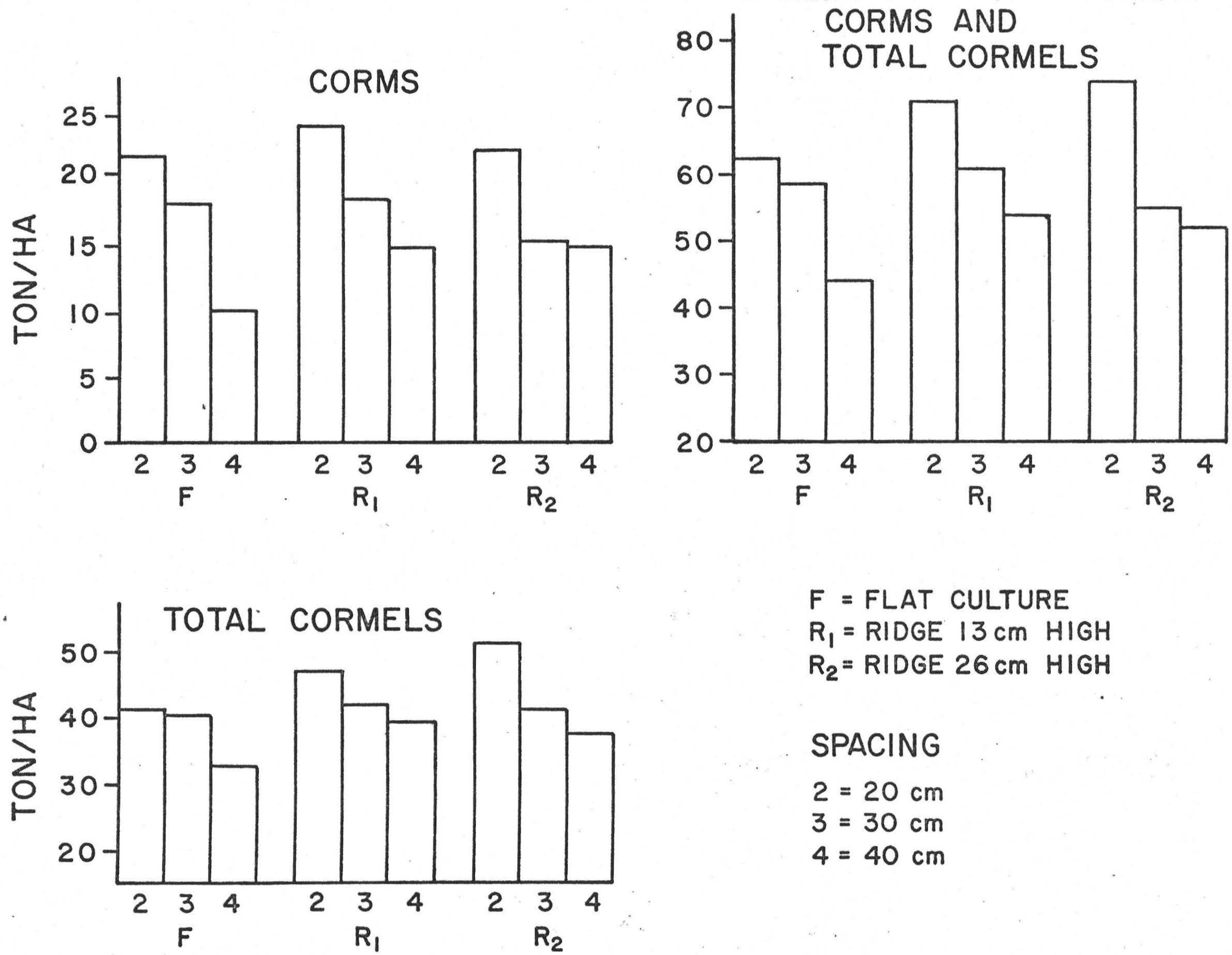


Figure 16. Effect of land preparation x plant spacing on taro yield at 12 months.

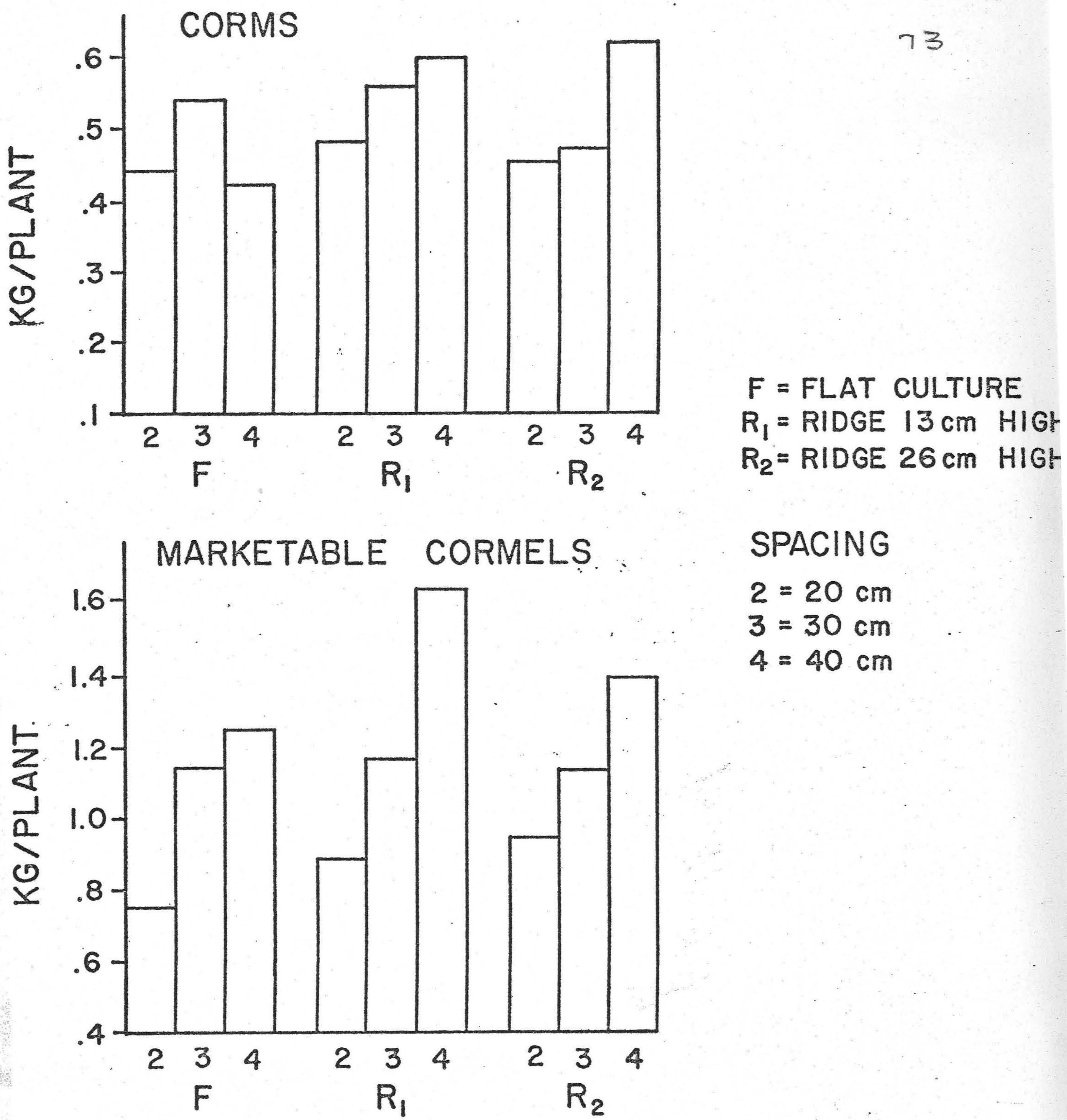


Figure 17. Effect of land preparation x plant spacing on taro yield at 12 months.

as well as its subsequent performance due to less light, unfavorable temperatures and pH. In taro, however, approximately half of the planting material (leaves and psuedostem) is exposed to sunlight and ambient temperature; hence there may be little yield difference between shallow and deep planting in the present study. Water would not be a limiting factor at the two depths since the entire field was flooded. Furthermore, two distinct layers are generally created upon flooding a soil (Ponnamperuma, 1955; De Datta, 1970; Patrick et al. 1971): (a) an oxidized layer in the top 1-2 cm and (b) an anaerobic layer containing reduced chemical ions such as manganese and iron at lower levels. This reduced layer was reported (Ponnamperuma, 1955) to be the zone of root development in rice. This was also observed to be true of taro roots based on their reddish-brown color at the time of harvest which corresponded to the color of reduced soil layer. This might be another possible reason for the lack of significant planting depth effect since most of the roots were probably exposed to the same pH and ion-rich reduced layer environments.

Another interesting observation made during harvesting was that corms under the shallow planting depth were rounder and more compact in shape (Figure 10b) compared to the slender base and 'pear' shape of the corms at the deep planting (Figure 10a). Cormels from deep planting were also more curved with a narrow hook-shaped posterior (Figure 10d) than those from shallow planting (Figure 10c). In potatoes, deep planting tended to produce tubers with a thinner skin than shallow planting (Arteschwager, 1924). This is not a desirable characteristic since such tubers can easily be attacked by pathogens.

Contribution of Corms and Cormels to Total Yield

The results shown in Tables 6 and 7 and Figure 12 show that cormels make a greater contribution to total yield than did corms. Similar results have been reported for taro (de la Pena, 1967; Ezumah, 1972). This is contrary to results obtained by Spence (1970) for tannia (*Xanthosoma sp.*) under different spacings. The greater contribution of cormels to the total yield is economically attractive since (a) most of the cormels can potentially be sold in the market (cormels weighing over 32g) in the raw form and (b) from field observations, cormels appeared to be less affected by corm rot caused by *Pythium* spp. Actually, if poi or flour is to be made, about 99% of the cormels can be utilized.

An interesting point reported by Leopold and Kriedemann (1975) is the translocation of materials from one developing potato tuber to another. Some tubers may even transfer all their materials into other tubers. This needs to be investigated in taro. If materials can be moved freely from corms to cormels, more uniform cormels might result. Furthermore, if materials can be moved from one cormel into another, particularly from the very small ones, marketable cormel yields might be increased. Total cormel yields might also be increased since very small cormels are often discarded during harvest. The possibility that growth regulators might be involved in this process of translocation exists and awaits exploration.

Land Preparation X Planting Depth

None of the interactions between land preparation and planting depth were significant at either the 10 or 12 month harvest (Appendix Tables 27-31).

Spacing X Planting Depth

Spacing by planting depth yield interactions were not significant at 10 months (Appendix Tables 27 and 32).

However, interactions between spacing and planting depth for marketable and total cormel yields at 12 months were highly (1% level) significant (Figure 18 and Appendix Table 28). Total corms and cormel yields were significant at the 5% level (Figure 18 and Appendix Table 28). There appeared to be no consistent pattern in the data; for instance at the 20 and 30 cm spacings, total cormel yield was higher under the deep planting whereas under the wide plant spacing, the reverse was observed. Deep planting, however, consistently out-yielded the shallow planting under the medium (30 cm) spacing. A possible explanation is the higher number of suckers produced under the deep than the shallow planting. Furthermore, more leaves were produced under the deep than the shallow planting which could have resulted in more photosynthates and hence a higher yield, assuming that translocation into the underground storage organs was not a limiting factor.

Land Preparation X Spacing X Planting Depth

Interactions among land preparation method, spacing and planting depth are shown in Appendix Tables 27-29; 33 and 34. None of these was significant at either 10 or 12 months.

Relation of Canopy Morphology on Yield

Leaf area index is often considered to be the best single parameter that can be used to predict light interception and dry matter yield of crops (Watson, 1958; Wilson and Teare, 1972). Grain, fruit or tuber yields often increase with increasing leaf area index or planting

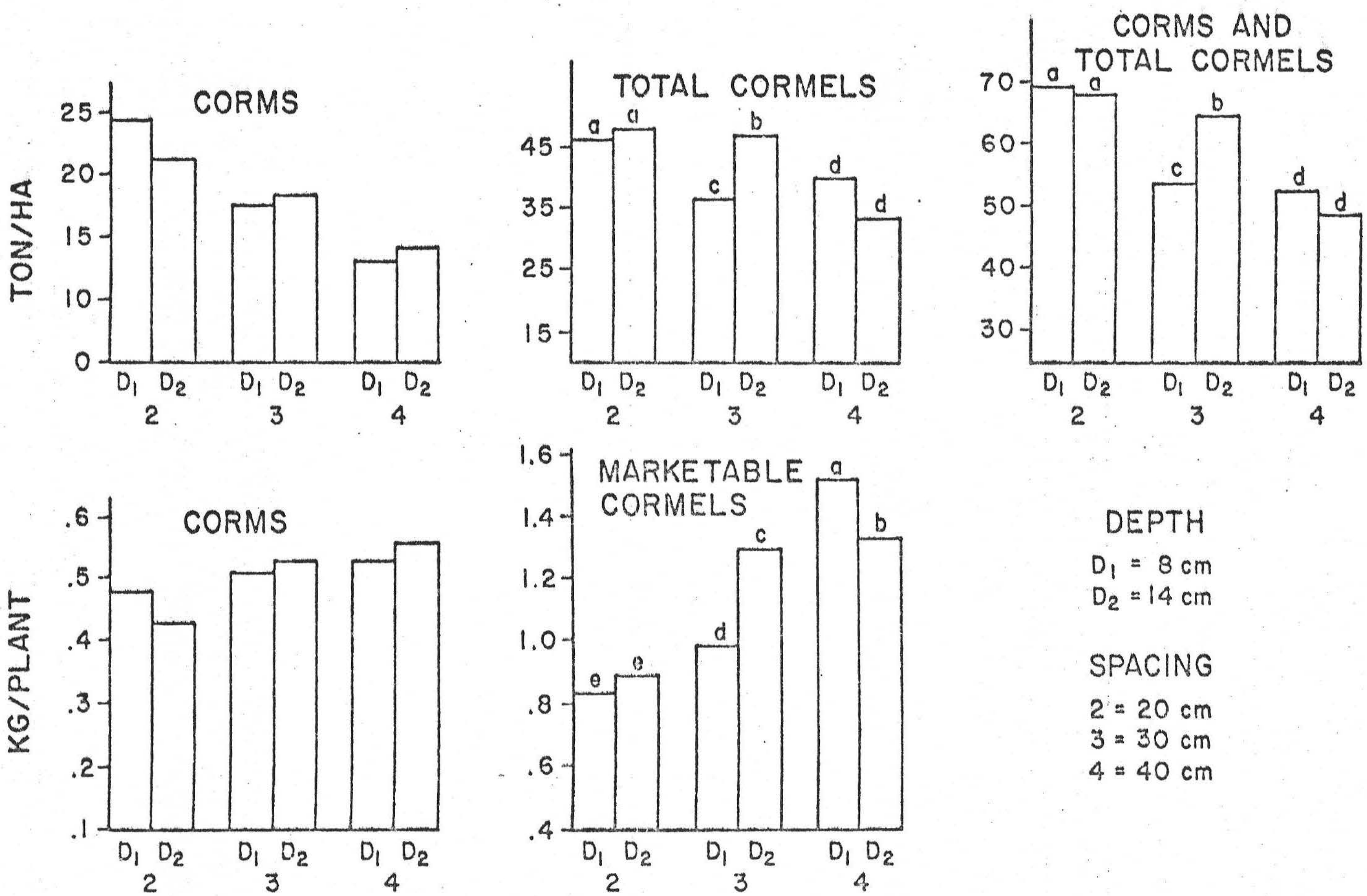


Figure 18. Effects of plant spacing and planting depth on taro yields at 12 months. (Yields without or having the same letter are not significantly different from each other within spacing; BLSD P = 0.05).

density up to a maximum and then decline.

Correlations between certain leaf measurements and suckers per plant and taro total yields at 12 months are presented in Table 8. In general, the relationships are rather poor as indicated by the low correlation coefficients (r). The low correlations of leaf area per plant or leaf linear measurements per plant and yield were probably due to the treatments involving high planting densities. This is indicated by the fact that as the number of plants per hectare decreased or space between plants increased, the 'r' values improved (Table 9). Reddy et al. (1968) have done correlation studies on taro, Colocasia esculenta, yields (g) versus leaf area, cm^2/plant and leaf linear measurement 'A' (cm) which was used in the present study. Their 'r' values for leaf area and linear measurement on corm yields were 0.569** and 0.406** respectively. Plant spacing was not indicated. Ezumah (1972) obtained 'r' values of 0.83**, 0.56** and 0.54** at three, five and seven months respectively after planting for total leaf area versus corm yield at 13 months. His spacings were wider than those of the present study.

The low correlation between yield and MP-LAI obtained for this study was probably due to the fact that mother-plant LAI (MP-LAI) was employed since leaves of suckers were not available. The 'r' values for MP-LAI at three and five months on total yields in the present study are 0.74** and 0.65** respectively. Ezumah (1972) obtained an 'r' value of 0.93** between LAI at five months and total yields at 13 months under flood irrigation.

Tables 8 and 9 show a positive linear relationship for both leaf area per plant and MP-LAI on yield whereas the relationship between suckers per plant and yield was negative. This negative relationship

Table 8. Coefficients of Correlation between Taro Yields at 12 Months and Certain Traits

T R A I T	Months[1/]	Corms	Cormels	Total Yield
Leaf area, dm^2/plant	3	0.20	0.39**	0.35**
Leaf area, dm^2/plant	5	0.06	0.27*	0.21
Leaf area, dm^2/plant	7	-0.04	0.30*	0.19
Leaf area, dm^2/plant	9	0.02	0.23	0.17
Leaf length A, cm[2/]	3	0.20	0.38**	0.35**
Leaf length A, cm	5	0.06	0.27*	0.22
Leaf length A, cm	7	-0.08	0.26	0.15
Leaf length A, cm	9	0.03	0.25	0.19
Mother-plant LAI	3	0.73**	0.63**	0.74**
Mother-plant LAI	5	0.70**	0.51**	0.65**
Suckers per plant	3			-0.04
Suckers per plant	5			-0.20
Suckers per plant	7			-0.58**
Suckers per plant	9			-0.15

[1/]Months after planting; [2/]See Figure 3 for dimension A.
n 54; *, ** Significant at 5 and 1% levels respectively.

Table 9. Regression Equations and Correlation between Taro Total Yields (Corms + Cormels) (Y) at 12 Months and Certain Traits ('r' Values)

TRAIT	Months after planting	SPACING, CM 20	30	40
Mother-plant LAI	3	0.311	0.657	0.867**[1/]
Leaf area, dm^2/plant	3	0.402	0.446	0.817**[2/]
Leaf area, dm^2/plant	5	0.113	0.421	0.884**[3/]
Suckers per plant	7	0.329	0.142	-0.722*[4/]

1/ $Y = 11.89 + 29.02X$

2/ $Y = 1.99 + 3.91X$

3/ $Y = 13.88 + 5.41X$

4/ $Y = 148.14 - 5.46X$

may have been due to the fact that beyond a certain period, any new suckers produced would not produce cormels that would be large enough to be included in the yield determination. Furthermore, suckers would probably obtain their food materials from the mother plant until they have produced and developed a good root system and leaves. This strain exerted on the mother plant is more pronounced under the wide plant spacing (cm) because of its production of more suckers per plant. This is reflected in its negative 'r' value (Table 9). Cormels were still developing in most suckers at time of harvest.

The results shown in Tables 8 and 9 suggest that if relative total taro yields are to be predicted at 12 months on the basis of the traits listed, MP-LAI at three months might be selected. Spence, as cited by Ezumah (1972), stressed the significance of attaining a large leaf area as early as possible in Xanthosoma. An early rapid maximum vegetative growth followed by a decline in vegetative growth as underground storage organs develop is a general characteristic of root crops such as taro (Ezumah, 1972), yams (Chapman, 1965) and Irish potatoes (Chapman, 1965). This is apparently due to a translocation of assimilates from the vegetative organs to the underground storage organs. It would therefore appear that for maximum underground storage organ efficiency, leaf indexes in taro should be both large initially and be maintained at values obtained at three and five months after planting. This means, among other things, a consideration of plant spacing as well as time of fertilizer application because of their effects on leaf area production.

Interestingly, growth regulators, such as gibberlic acid have been used to manipulate leaf production for better yields in sugar beets (Humphries and French, 1965). There is also considerable evidence in the literature which suggests that an increased demand for assimilates (sink effects) might increase photosynthetic rates (Humphries and French, 1965; Spence, 1970) of different crops. Thus taro corm and cormel yields may be increased by manipulating, among other things, vegetative production through plant spacing, size of hulis, land preparation techniques, method and time of fertilizer application and use of growth regulators.

WATER REGIME EXPERIMENT

Effect of Length of Flooding on Yield

0 = Continuous flooding (12 months)

2 = Water drained 2 months before harvest

4 = Water drained 4 months before harvest

Results of corm and cormel yields at 12 months are shown in Table 10. Both corm and total yields increased with increased length of flooding. Highest corm and total yields (36.13 and 79.98 ton/ha, respectively) were obtained under the 0 treatment; whereas highest marketable and total cormel yields, 49.14 and 50.05 ton/ha respectively were obtained under treatment 2. The higher yield of cormels under treatment 2 than treatment 0 might be due to the production of more number of cormels (Table 10). However, the highest total yield was produced under continuous flooding. This is due to the contribution by corms.

Superior yields under continuous flooding have also been reported in rice (De Datta *et al.* 1970) and in taro (Ezumah, 1972). Work by de la Pena (1967) on taro (Lehua variety) grown under flooding and dryland conditions has also shown superior yields under flooded than

Table 10. Influence of Water Regime on Taro Yields at 12 Months

YIELD TRAIT	WATER REGIME[1/] 0	2	4
	TONS PER HA		
Total corms[2/]	36.13	25.40	18.14
Marketable cormels	42.94	49.14	38.26
Total cormels	43.84	50.05	39.16
Total yield	79.98	75.45	57.31
Number of cormels/ha	304,759	384,479	333,868
Rotten corms (%)	88	51	45

[1/] 0 = Continuous flooding

2 = Water drained 2 months before harvest

4 = Water drained 4 months before harvest

[2/] All corms would be marketable except when severely rotten.

dryland under comparable fertilizer applications. De Datta *et al.* (1970) have reported that water affects the physical character of the rice plants. For instance, plant height is directly related to the depth of water in the field. Lower grain yields of rice under dryland culture have been attributed to a number of factors: (a) competition by weeds, (b) lack of a variety adapted to dryland culture and (c) poor insect and/or disease control. Superior yields of flooded rice might be due to (a) higher tissue hydration, (b) water use efficiency, (c) lower evapotranspiration rate and (d) increased nutrient availability because of greater nutrient mobility in the flooded soil-solution. Also, the large quantity of water could serve as a diluent which would bring about increased solubility of B,Mo,Co,Cu and Zn which are present as sparingly soluble compounds (Villegas *et al.* 1970; Patrick and Mikkelsen, 1971).

A release of P due to increased solubility of Mn,Fe and Al (Ca,Mg and Zn often depressed) has also been implicated under flooded conditions (Cherian *et al.* 1968) whereas under upland aerated conditions, P is chemically bound by the soil. Similar advantages may be obtained when taro is grown under flooded culture.

The fact that many corms were partially or totally rotten in this study, and the fact that corms in the adjacent fields were also rotten, furthermore seems to point to the flood as a major causal agent since fresh water circulation was adequate in the water regime plots because of their small size. Another possibility was that some of the planting material might have been infected.

Estimation of Labor Requirement in Harvesting

Table 11 shows an estimation of the time required to harvest taro. The plots that were in treatment 2 required the most labor. This was because the soil was only partially dry and therefore roots were held tightly compared to the flooded plots in treatment 0 in which standing water helped to loosen the soil. Soil in treatment 4 was dry and roots had deteriorated, which meant less time was involved in harvesting as compared to the other two treatments. The above differences in root and soil characteristics were also responsible for the time differences required in removing roots from the corms and cormels.

Labor requirements for production of tropical root crops are generally high. For example, the production of yams in Nigeria, Ghana and Trinidad required 360, 456 and 280 man-hours per ton respectively (Coursey, 1967) compared to 7.6 to 16 man-hours per ton for production of Irish potatoes in Great Britain. Thus, these high labor requirements and inability to meet consumer demand due to shortage of labor has led to increased interest in mechanization by farmers, particularly with respect to planting and harvesting.

Estimation of Poi Fermentation Rates

The process of fermentation, the breakdown of carbohydrates and carbohydrate-like materials in the presence or absence of oxygen (Potter, 1973) occurs naturally. In developing countries, fermentation and smoking are the two major methods of food preservation. Furthermore, fermentation provides variety to the diet, provides complex vitamins and releases nutrients that might exist in complex forms such as cellulose (Potter, 1973).

Table 11. Effect of Water Regime on Man-Hours Required to Harvest One Hectare of Taro, 30 x 100 cm, at 12 Months

PROCESS	WATER REGIME[1/] 0	2	5
	MAN-HOURS/HECTARE		
Pulling out taro	305.6	844.4	300.0
Removal of roots from corms and cormels	938.9	1372.2	961.1

[1/] 0 = Continuous flooding

2 = Water drained 2 months before harvest

4 = Water drained 4 months before harvest

A characteristic of fermentation is a decrease in pH, and the importance of fermentation in this study lies in the fact that fermented poi from taro corms is an important food in Hawaii. Poi quality depends, among other things, on its texture and acidity (Allen and Allen, 1933).

Results in Figure 19 show increased acidity or decreased pH with storage. The pH decreased from a maximum of 6.02 on day one to a minimum of 3.67 on day nine. In general, rate of fermentation as shown by increased acidity, (Figure 19) and amount of solids in corms and cormels (Table 12) increased slightly with length of flooding. This might suggest that quality of poi tends to decrease with decreased length of flooding. Similar results have been obtained (unpublished data of Miss Catherine Cavaletto). A decrease in pH from 6.3 to 4.5 during the first 24 hours of fermentation has been reported (Allen and Allen, 1933); that acidity increased up to the sixth day whereas sugars decreased rapidly early in the process. That acidity continued to increase up to the ninth day of fermentation in the present study was probably due to the storage temperature of approximately 24.4 C. Rate of fermentation greatly depends on temperature (also levels of oxygen and salt). At a higher temperature, the rate of fermentation would be enhanced to the extent that pH would reach a minimum value before the ninth day. Allen and Allen (1933) have suggested that during the period of acid production, a large amount of starch is hydrolysed and converted into readily available energy. The unpleasant taste and odor of old poi has been considered to be caused by butyric acid (Bilger and Young, 1935), one of several products of poi fermentation. Other products are CO_2, alcohol, acetaldehyde and lactic, acetic and formic acids.

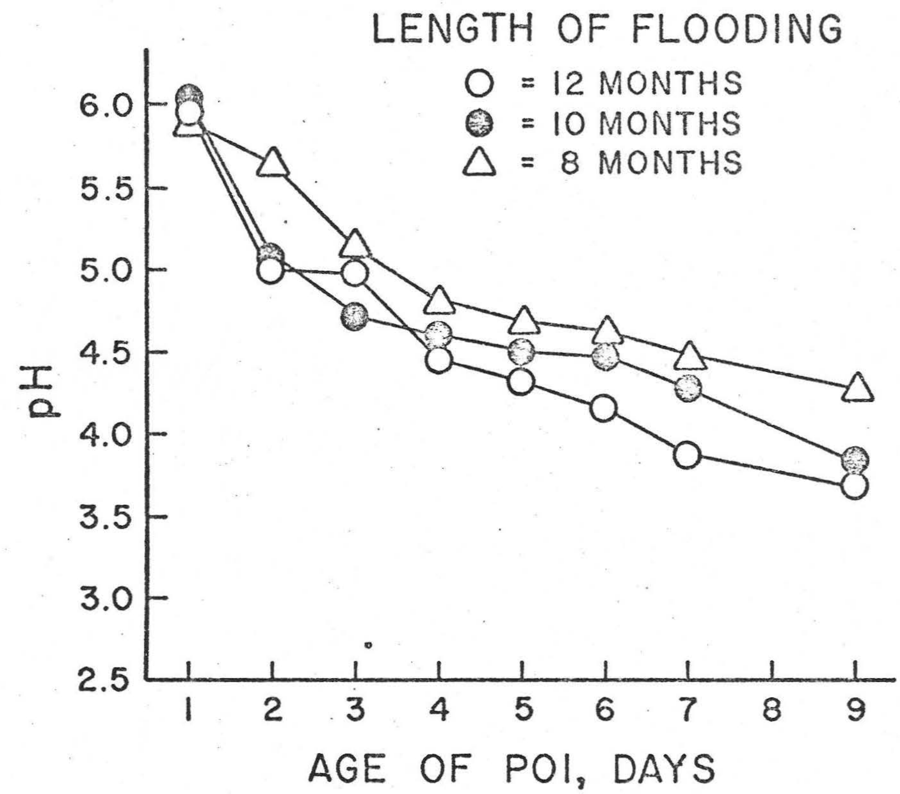


Figure 19. Relation of age of poi on pH of poi when stored at approximately 24.4 C.

Table 12. Influence of Water Regime on Yield and Other Traits of Taro at 12 Months

TRAIT	WATER REGIME[1/] 0	2	4
Corm + cormel fresh weight, g	69.58	74.46	73.49
Total solids in corms + cormels, %	53.41	52.87	52.37
Peeled corms + cormels, kg	4.55	3.64	3.64
Poi recovered, kg	5.00	4.32	3.75
Sample fresh poi, g	27.48	26.82	34.00
Solids in poi sample, %	27.00	27.18	25.29

[1/] 0 = Continuous flooding
2 = Water drained 2 months before harvest
4 = Water drained 4 months before harvest

Effect of Flooding on Flavor and Color of Poi

Poi (one day old) flavor and color were evaluated on the basis of taste and appearance respectively. The taste panel showed flavor preference for poi prepared from taro corms and cormels in the order 0 > 4 > 2; whereas preference for poi color was in the order 0 > 2 > 4. However, the differences among the three treatments were not significant for both traits (Appendix Table 38).

There was a positive correlation between poi flavor and color (Figure 20) particularly for treatments 2 (0.89**) and 0 (0.71*). This may not be surprising since in most cases people eat food that has an attractive color. The observation was made that poi made from treatment 2 had a pinkish or reddish color whereas poi made from treatment 0 and 4 had a somewhat grayish color (Figure 21). Thus, though the differences among the three water regimes were not significant for either flavor or color of poi, the results suggested a general preference for poi made from treatment 0. However, if the taro industry in Hawaii is expanded, it might be possible to make other products from taro with the result that other water management regimes such as intermittent flooding could be adapted.

The future of the taro industry in Hawaii is quite dependent on mechanization, particularly for harvesting, from the stand-point of both production costs and appeal to young farmers. Mechanical harvesting in turn is dependent on a compromise between paddy culture and dryland culture.

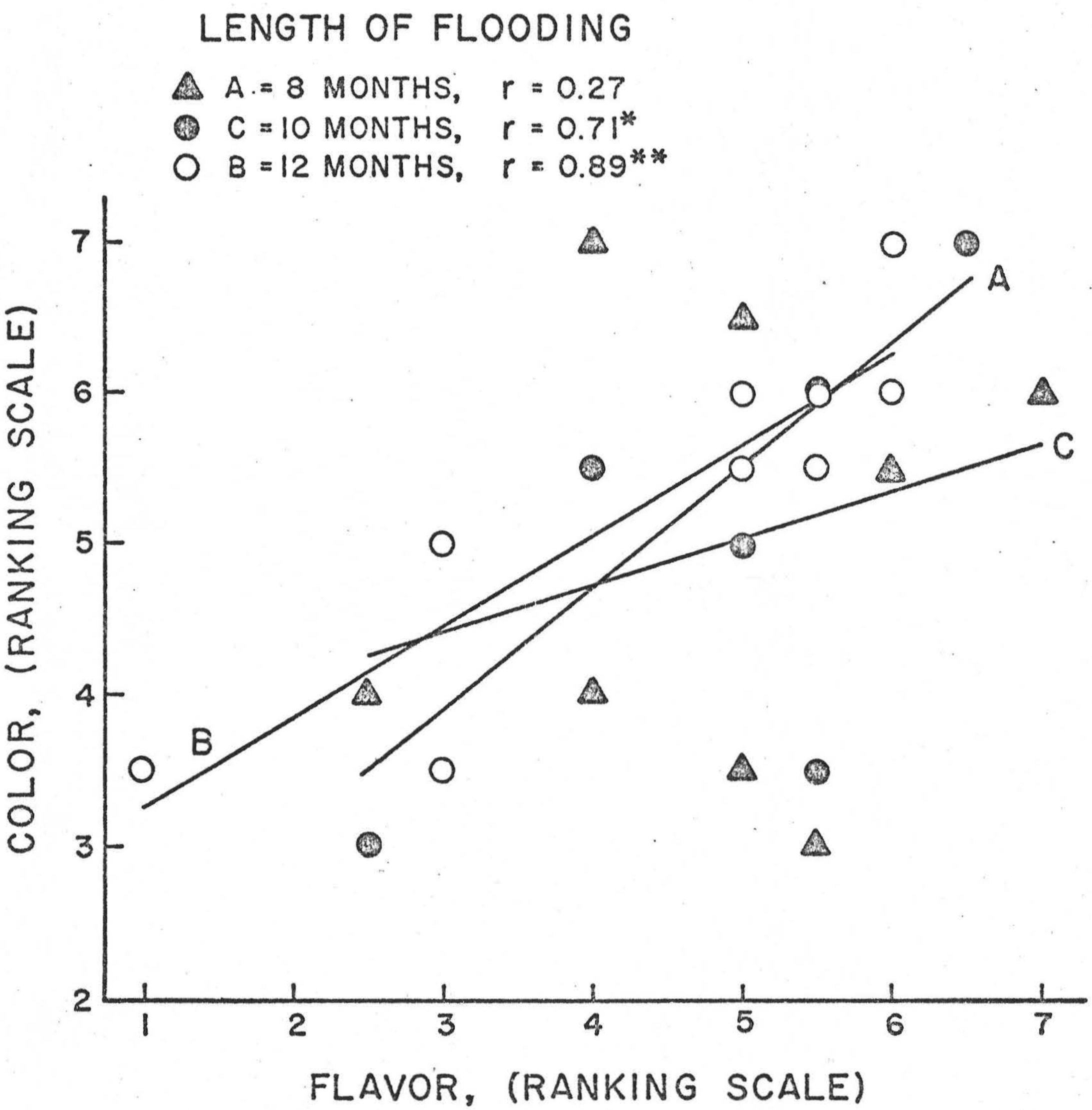


Figure 20. Correlation between flavor and color of poi.

Figure 21. Effect of water regime on color of poi refrigerated for three days.

0 = Continuous flooding (12 months)

2 = Water drained 2 months before harvest

4 = Water drained 4 months before harvest.

POT STUDIES

These studies were designed to obtain information on the influence of climatic regime, planting depth and type of huli on the growth of taro.

Effects of Temperature, Shade and Full Sun on Morphological Characters: Leaves, Petioles, Leaf Area and Suckers

Light and temperature are two environmental factors that influence, among other things, the synthesis of chlorophyll, growth substances, carbohydrates, number and position of chloroplasts, opening and closing of stomates and transpiration (Weaver and Clements, 1938; Leopold and Kriedemann, 1975).

Results in Table 13 show a decrease in number of leaves, length of petioles and leaf area per plant under full sun. Shaded plants have consistently been reported to be taller with greater leaf area than those in full sun (Weaver and Clements, 1938; Watson, 1952). Maximum vegetative expansion and height are obtained at 50% full sun (Leopold and Kriedemann, 1975). Since the amount of shading in the greenhouse and outside + saran was nearly comparable, the slightly higher vegetative production in the greenhouse than outside + saran may have resulted from the higher temperatures in the greenhouse (Table 14). The higher vegetative growth under the saran than full sun was probably due to shading since temperature was comparable under the two conditions. More vegetative growth with increasing temperatures has also been reported for Irish and sweet potatoes (Hozyo, 1970; Sekioka, 1970; de Geus, 1973). Both photosynthesis and leaf expansion are optimized at 24 C (Leopold and Kriedemann, 1975). Shaded plants can achieve maximum photosynthesis by producing large leaf areas.

Table 13. Influence of Shading on Numbers of Leaves, Suckers, Length of Petioles and Leaf Area per Plant in Taro Grown in Pots*

CONDITION	Number of Leaves			Number of Suckers				Petiole Length cm				Leaf area, dm^2		
MONTHS AFTER PLANTING	2	3	4	2	3	4	5	2	3	4	5	2	3	4
Greenhouse + 51% Shade	5.8	4.3	4.1	1.9	2.8	4.5	5.3	63.0	82.6	95.1	90.8	11.0	13.4	14.9
Outside + Saran (45%) Shade	5.9	4.2	3.6	2.9	5.2	5.6	5.5	55.8	75.1	78.9	71.9	10.0	15.6	14.0
In Full Sun	5.0	4.1	3.2	3.2	4.9	5.1	4.9	48.4	64.7	66.5	56.6	8.2	11.6	10.5

*Data not analysed statistically.

Table 14. Mean Monthly Maximum and Minimum Temperatures for the Taro Pot Studies

	PLACEMENT OF POTS					
	Greenhouse + 51% Shade		Outside + 45% Saran Shade		In Full Sun	
	TEMPERATURES oC					
MONTH	max.	min.	max.	min.	max.	min.
			1974			
November (23-30)	35.4	18.3	31.4	18.6	29.6	17.9
December	33.6	17.9	27.4	18.7	26.8	19.1
			1975			
January	31.2	16.6	26.9	16.3	26.3	15.9
February	29.2	17.4	27.8	17.7	25.1	16.7
March	28.9	17.4	25.2	16.8	24.4	17.2
April	31.6	17.9	25.6	17.3	24.7	17.8
May	34.2	18.5	26.2	17.9	25.6	18.3
June (1-14)	36.4	19.6	26.4	19.4	26.0	20.3
Means	32.6	17.9	27.1	17.8	26.1	17.9

Temperatures were recorded by a Tempscribe Bimetal Recorder model STA.

Work on sugar beets, potatoes and other root crops by Humphries and French (1965), Humphries (1967) and Milthorpe (1967) has indicated a translocation of photosynthates from the vegetative parts into the underground storage organs. High temperatures are therefore desirable during the early phase of growth of taro. Spence (1970) has stressed the importance of producing large leaf areas in the early phase of tannia (*Xanthosoma*) development.

Number of suckers increased with time under all three conditions. The slightly greater production in number of suckers with saran than greenhouse was probably a temperature effect (Table 14). The decrease in number of suckers at five months for all three conditions was because the youngest suckers died a few weeks after emergence, probably due to mutual shading by the mother-plants and older suckers and/or to competition for nutrients.

Petiole, Leaf Blade and Root Weights

Fresh and dry weights of petioles, leaf blades and roots were higher under shade than full sun (Table 15). The higher weights observed for greenhouse treatments than for saran shaded treatments were apparently due to the higher temperatures attained in the greenhouse (Table 14). On the other hand, the higher fresh and dry weights observed for the saran shaded treatments than for those receiving full sun were apparently due to shading since temperatures were comparable. The combined effects of shade and increased temperatures are reflected in the weight differences between treatments in the greenhouse and those in full sun. The fact that the increase in dry matter was less between full sun and saran shaded treatments than between saran shaded

Table 15. Influence of Shading and Full Sun on Yield of Taro Grown in Pots, at 7 Months*

YIELD CHARACTER	Greenhouse + 51% Shade	Outside + 45% Saran Shade	In Full Sun
Petiole fresh weight, g/pot	292.06	152.82	101.70
Petiole dry weight, g/pot	22.42	12.49	8.96
Leaf blade fresh weight, g/pot	62.13	42.66	30.73
Leaf blade dry weight, g/pot	7.22	4.72	3.65
Root fresh weight, g/pot	382.00	375.00	320.42
Root dry weight, g/pot	34.61	27.40	25.52
Total fresh weights of leaves, roots, corms and cormels, g/pot	1486.19	1330.48	1122.85
Dry weights of leaves and roots, g/pot	64.25	44.61	38.13

*Data not analysed statistically.

treatments and greenhouse treatments suggests that increased temperature had a greater effect on dry matter production than did reduced sunlight (shade).

Corm and Cormel Yields

The yield results in Table 16 raise some interesting thoughts. Although cormel yields among the three conditions were not significantly different, saran shaded treatments had the highest yields. The fact that both cormel and total yields under saran shaded treatments were slightly higher than greenhouse pots, but greenhouse pots consistently out-yielded those under saran for vegetative and root production seems to suggest that vegetative and root growth in the greenhouse occurred without comparable growth of underground storage organs. Also, higher temperatures cause higher rate of respiration which utilizes photosynthates, leaving less for storage organs. Temperature was lower with saran shade than in the greenhouse. Lower temperatures have been reported to favor growth of underground storage organs (Humphries, 1967; Milthorpe, 1967; Hozyo, 1970; Sekioka, 1970; de Geus, 1973).

The higher yields of the shaded plants in the greenhouse and saran than those in full sun may be unexpected since radiant energy supply usually affects carbohydrate production. However, leaves of plants in full sun were partly damaged by the strong winds of the experimental site; whereas the saran and glass enclosing the greenhouse minimized the wind effect in the case of the shaded plants. If no other factors were limiting the yields of plants in full sun, it may be that the greater vegetative growth of plants under saran and greenhouse resulted in a greater translocation of photosynthates for development of corms

Table 16. Influence of Shading and Full Sun on Yields of Taro Grown in Pots, 7 Months after Planting

YIELD COMPONENT	CONDITION		
	Greenhouse + 51% Shade	Outside + 45% Saran Shade	Full Sun
Number of cormels/pot	5.3a	5.2a	4.7a
Cormels, kg/pot	0.20a	0.22a	0.21a
Corms, kg/pot	0.55a	0.53a	0.47b
Total yield, kg/pot	0.75a	0.76a	0.67b

Means in the same row followed by the same letter are not significantly different at the 5% (BLSD) level.

and cormels, hence higher yields. Spence (1970) has emphasized the importance of producing a large vegetative growth during the early stage of Xanthosoma since greater photosynthetic leaf area might be advantageous in making more photosynthates for corm growth.

Effects of Planting Depth and Type of Huli Within Greenhouse + 51% Shade, Outside + 45% Saran Shade and Full Sun

Leaves, Petiole Lengths, Leaf Area and Suckers/Plant

In general, number of leaves per plant decreased from the second month after planting (Figure 22) whereas petiole lengths and leaf blade area/plant steadily increased from planting to the third and fourth months after planting and then declined (Figures 23 and 24). Similar results were obtained in the field experiment of the present study and by Spence (1970) in Xanthosoma. Number of suckers on the other hand increased from planting up to four months after planting and then either continued to increase, remained about constant or decreased (Figure 25).

The decrease in number of suckers/plant was due to the fact that the youngest suckers produced died a few days or weeks after emergence. This was probably the result of severe competitionfor nutrients and/or to mutual shading by the mother and older sucker plants. Leopold and Kriedemann (1975) cited studies which indicated a movement of materials from one developing potato tuber to another. The number of potato tubers may even decrease during the growing season due to a complete transfer of materials from some tubers into others. A similar mechanism might also be involved in taro. This phenomenon seems attractive from an economic stand point and needs further investigation since if very small cormels could empty their materials into the older ones, it would eliminate discarding them at harvest. However, this decrease in number

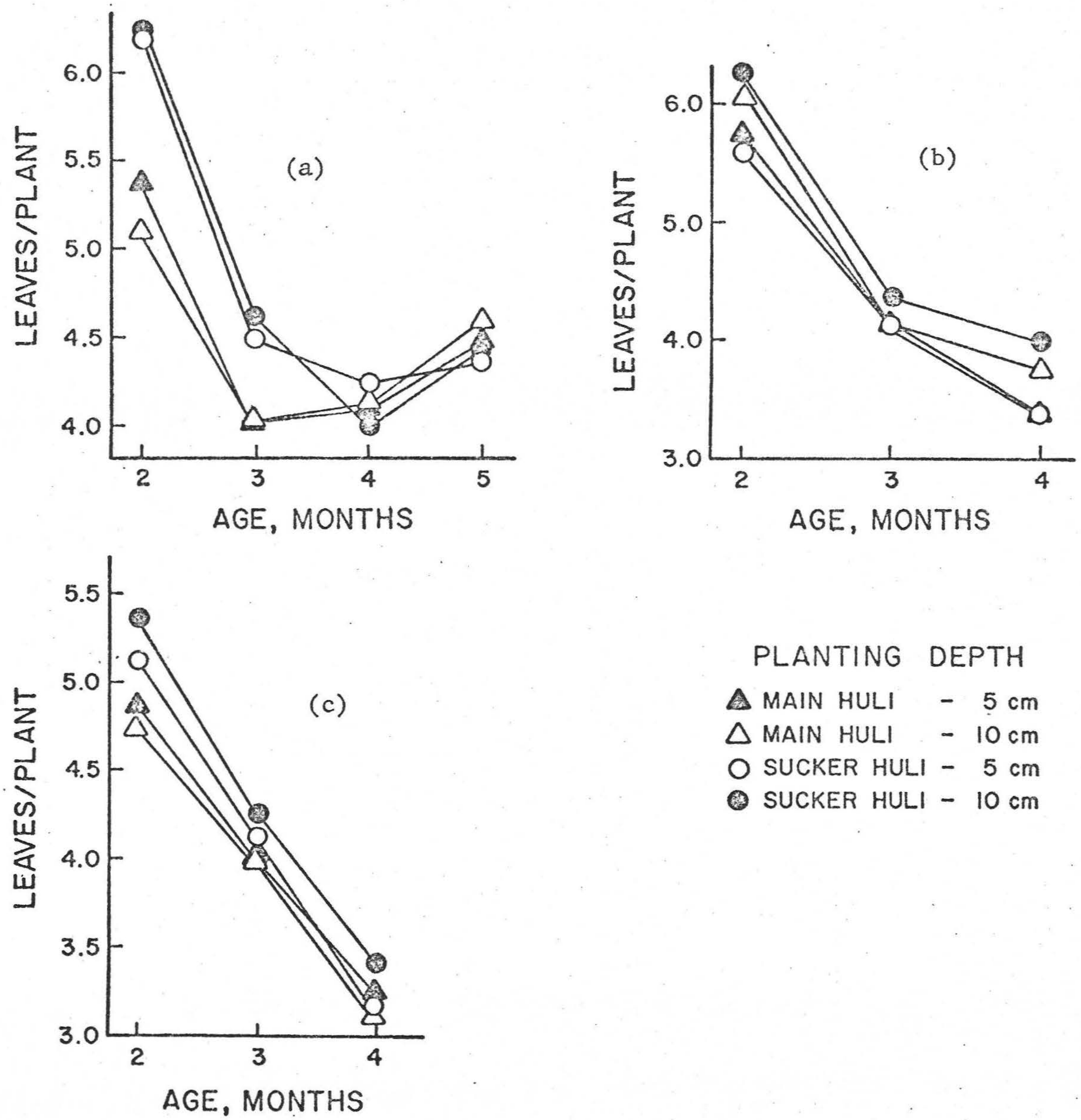


Figure 22. Effect of shading (a) greenhouse + 51% shade, (b) outside + 45% saran shade and (c) full sun on production of number of taro leaves per plant with time and grown in pots.

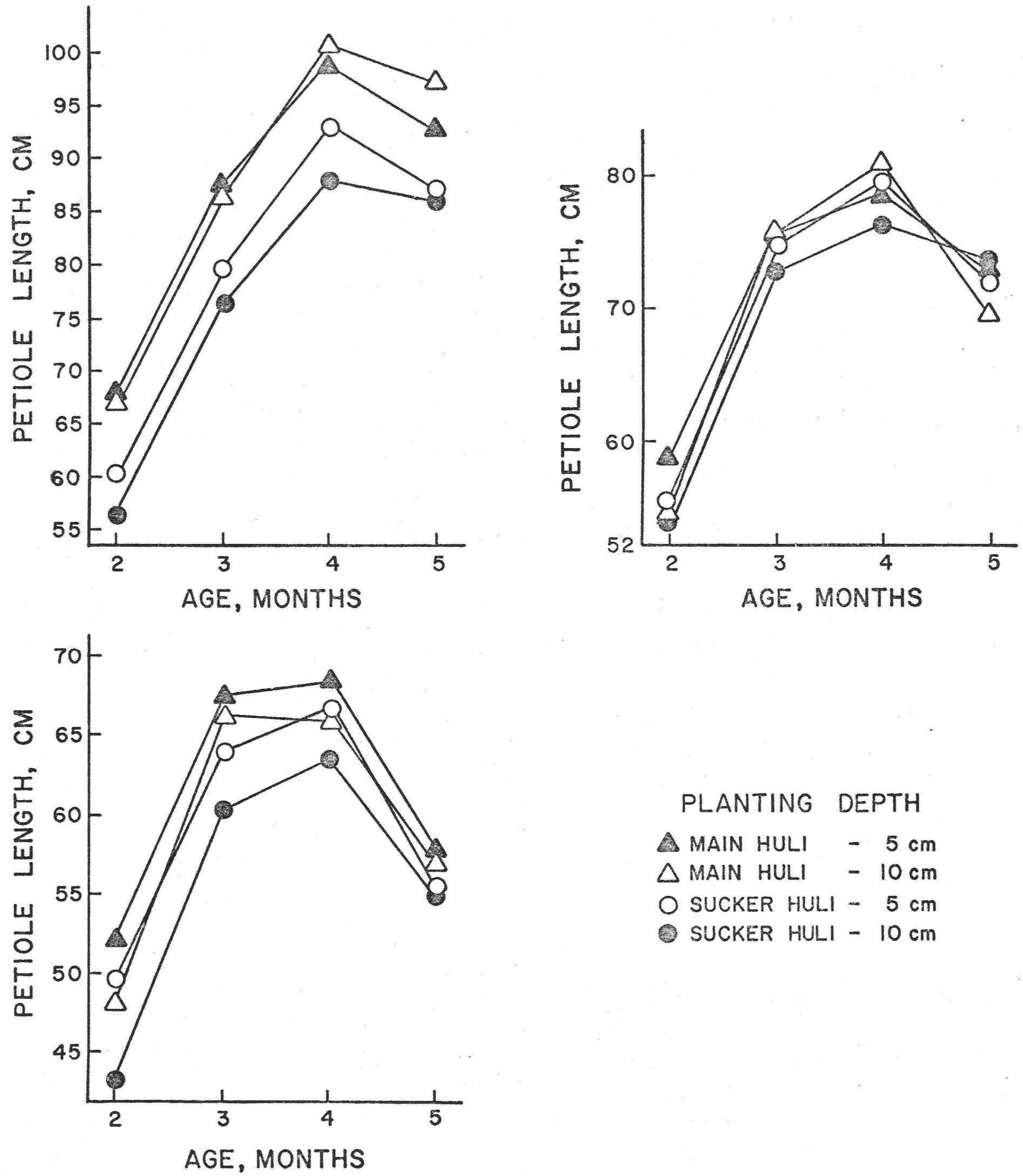


Figure 23. Effect of shading (a) greenhouse + 51% shade, (b) outside + 45% saran shade and (c) full sun on taro petiole lengths per plant with time and grown in pots.

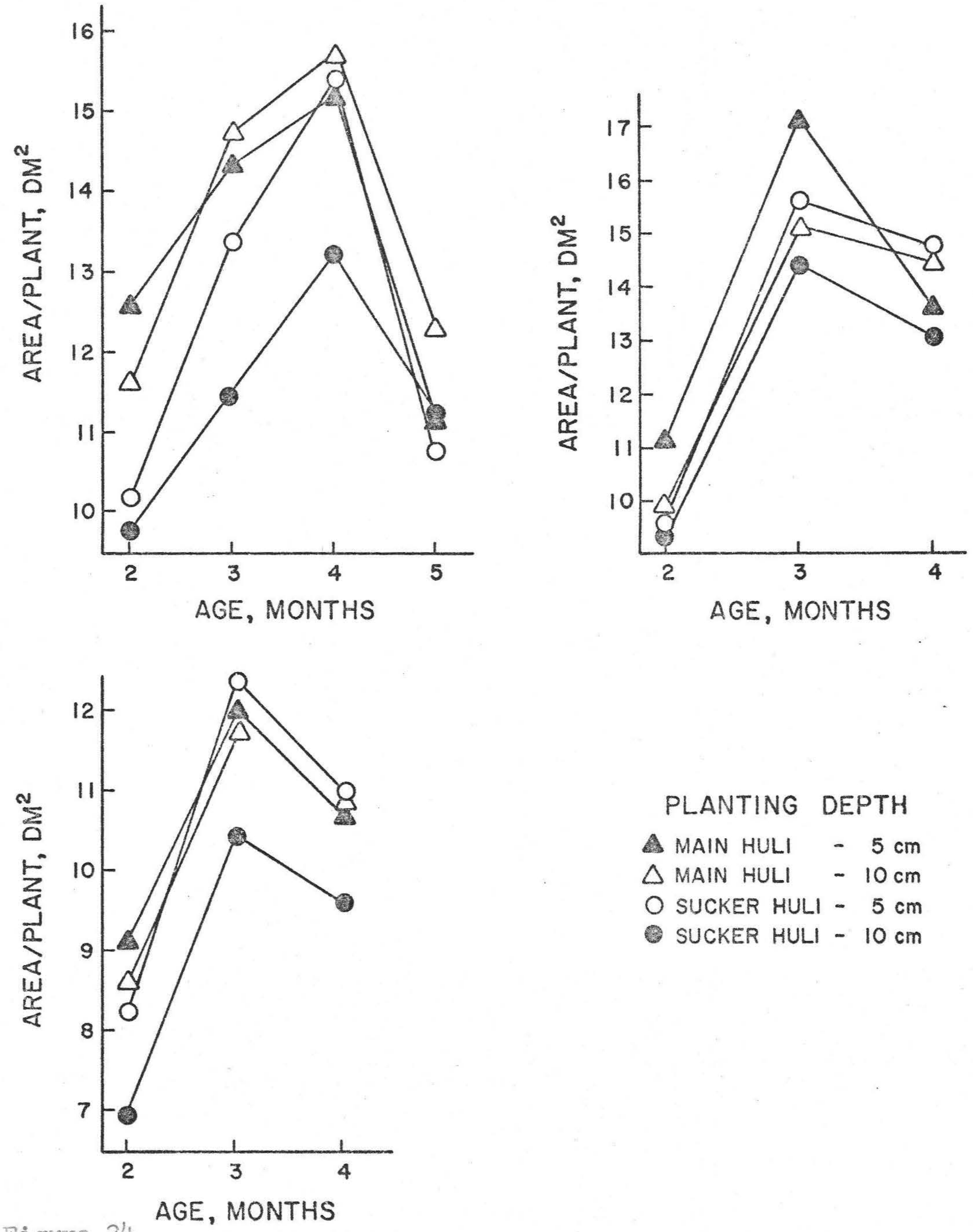


Figure 24.

Effect of shading (a) greenhouse + 51% shade, (b) outside + 45% saran shade and (c) full sun on taro leaf blade area with time and grown in pots.

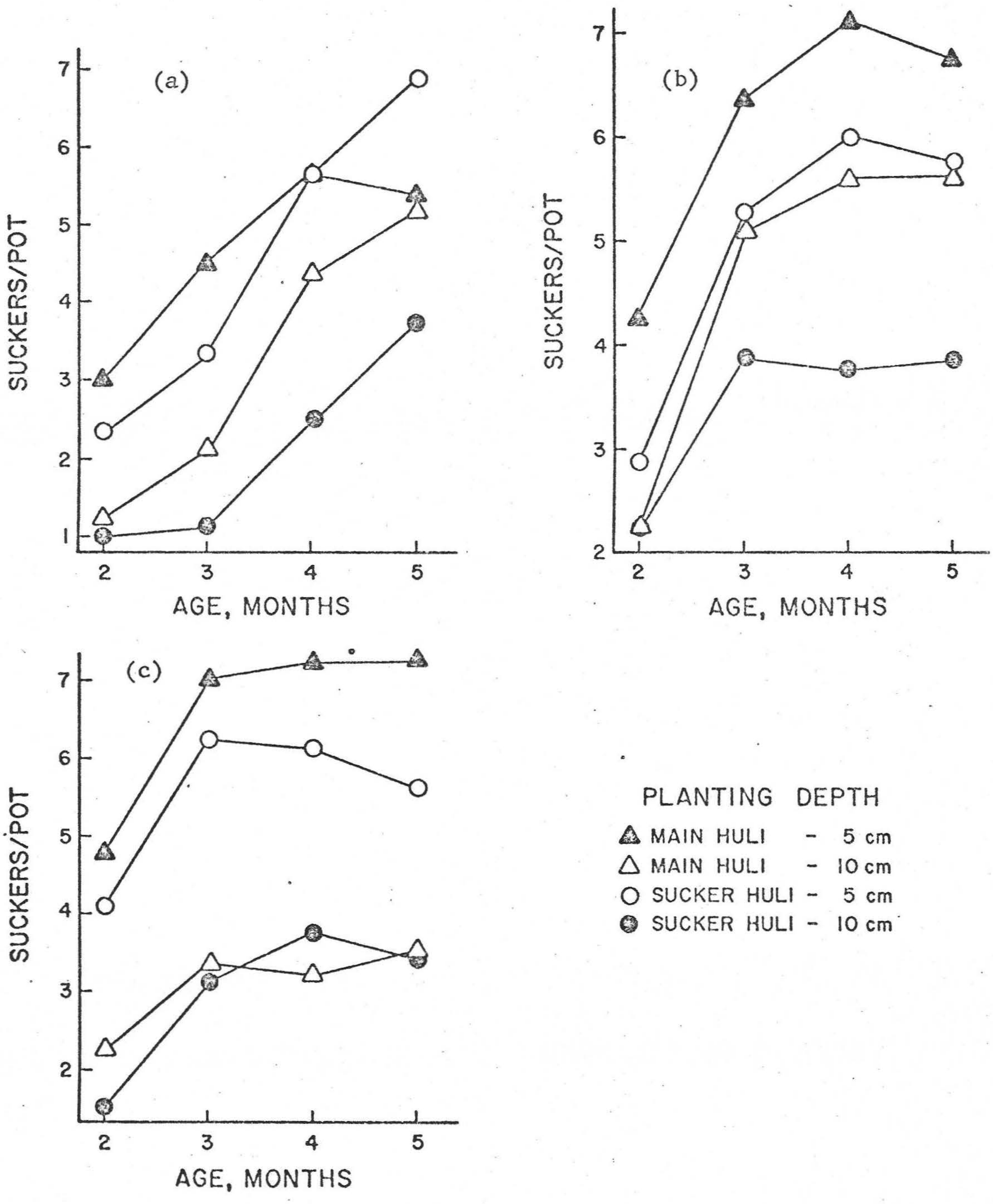


Figure 25. Effect of shading (a) greenhouse + 51% shade, (b) outside + 45% saran shade and (c) full sun on taro suckers/pot with time.

of suckers with time was not demonstrated in the results of the field experiment.

Greenhouse Pots + 51% Shade: Sucker hulis produced significantly more leaves per plant than main hulis at two and three months after planting (Table 17) whereas main hulis produced significantly longer petioles than sucker hulis at two to four months after planting. Main hulis also produced more suckers than sucker hulis.

Shallow planting produced significantly more suckers than deep planting (Table 18). This might be due to the shorter time required to emerge from the shallow planting and also greater exposure to light and temperature effects at the shallow depth.

Outside + 45% Saran Shade: Results in Table 17 showed a significant effect in production of suckers/plant due to type of huli. Perhaps main hulis had more buds than sucker hulis initially since buds develop into suckers. Shallow planting also produced significantly more suckers/plant than deep plantings (Table 18); again light and temperature may be involved.

Pots in Full Sun: Type of huli had no significant effect on production of leaves, suckers and leaf area except for petiole length at three months after planting (Table 17). However, shallow planting produced significantly more suckers/plant in the two to five month period, whereas petiole length and leaf blade area were significantly different only at two and three months after planting, respectively (Table 18).

Yield Characteristics

Results in Table 19 showed that in terms of both fresh and dry

Table 17. Influence of Type of Hulis on Some Yield Traits of Taro Grown in Pots under Different Amounts of Light

CONDITION AND TRAIT	MAIN HULI				SUCKER HULI			
	AGE IN MONTHS							
	2	3	4	5	2	3	4	5
GREENHOUSE + 51% SHADE								
Leaves/plant	5.3b	4.0b	4.1	4.6	6.3a	4.6a	4.1	4.4
Suckers/plant	2.1	3.4	5.0a	5.3	1.7	2.4	4.1b	5.2
Petiole length, cm	67.61a	87.20a	99.94a	94.96	58.36b	77.98b	90.31b	86.59
Leaf area, dm^2/plant	12.09a	14.25a	15.46	11.73	9.95b	12.44b	14.29	10.96
OUTSIDE + 45% SHADE								
Leaves/plant	5.9	4.1	3.6		5.9	4.3	3.7	
Suckers/plant	3.3a	5.8a	6.4a	6.2a	2.6b	4.6b	4.9b	4.6b
Petiole length, cm	56.67	75.84	80.04a	71.19	54.85	74.33	77.77b	72.58
Leaf area, dm^2/plant	10.54a	16.15	14.12		9.47b	15.04	13.90	
FULL SUNLIGHT								
Leaves/plant	4.8	4.0	3.2		5.3	4.2	3.3	
Suckers/plant	3.5	5.2	5.3	5.4	2.8	4.8	4.9	4.5
Petiole length, cm	50.31	67.05a	67.71	57.74	46.48	62.25b	65.31	55,36
Leaf area, dm^2/plant	8.88	11.86	10.76		7.59	11.38	10.28	

Means in the same row and for the same age followed by different letters are significantly different at 5% level.

Table 18. Influence of Planting Depth on Some Yield Traits of Taro Grown in Pots under Different Amounts of Light

CONDITION AND TRAIT	PLANTING DEPTH, CM: 5				10			
	AGE IN MONTHS							
	2	3	4	5	2	3	4	5
GREENHOUSE + 51% SHADE								
Leaves/plant	5.8	4.3	4.2	4.4	5.7	4.3	4.1	4.6
Suckers/plant	2.7a	4.1a	5.6a	6.0a	1.8b	1.8b	3.4b	4.5b
Petiole length, cm	64.05	83.61	96.01	89.65	61.91	81.56	94.24	91.90
Leaf area, dm^2/plant	11.64	13.87	15.29	10.95	10.69	12.83	14.46	11.74
OUTSIDE + 45% SHADE								
Leaves/plant	5.7	4.1	3.4b		6.2	4.3	3.9a	
Suckers/plant	3.6a	5.8a	6.5a	6.3a	2.3b	4.5b	4.8b	4.6b
Petiole length, cm	56.78	75.63	79.18	72.44	54.74	74.55	78.63	71.33
Leaf area dm^2/plant	10.36	16.39a	14.21		9.65	14.79b	13.81	
FULL SUNLIGHT								
Leaves/plant	5.0	4.1	3.2		5.1	4.1	3.3	
Suckers/plant	4.4a	6.6a	6.7a	6.4a	1.9b	3.3b	3.5b	3.4b
Petiole lengths, cm	50.95a	65.85	67.76	56.84	45.85b	63.45	65.26	56.26
Leaf area, dm^2/plant	8.67	12.17a	10.81		7.80	11.08b	10.24	

Means in the same row and for the same age followed by different letters are significantly different at 5% level.

Table 19. Influence of Type of Huli on Fresh and Dry Weight of Some Characteristics of Taro Grown in Pots, 7 Months after Planting

	Greenhouse + 51% Shade		Outside + 45% Shade		In Full Sun	
	TYPE OF HULI					
CHARACTER	Main	Sucker	Main	Sucker	Main	Sucker
	FRESH WEIGHTS, g/pot					
Vegetative parts, roots, corms and cormels	1573.0	1389.4	1411.1	1239.9	1216.0	1039.7
	DRY WEIGHTS, g/pot					
Vegetative parts and roots	67.8	60.7	49.6	39.6	44.2	32.0

Data not analysed statistically

weights of the components listed, main hulis consistently out-yielded sucker hulis. This needs to be investigated under field conditions, particularly since sucker hulis make up the greater part of the planting material. In relation to planting depth, there was no consistent pattern in the yield of the components listed in Table 20.

Greenhouse + 51% Shade: Main hulis tended to produce higher yields of all components listed in Table 21 than sucker hulis, however only corm + cormel yields were significantly higher. The significantly higher yield of main hulis than sucker hulis might be explained by the fact that main hulis produced more suckers, greater leaf area and longer petioles per plant than sucker hulis (Table 17). Also, deep planting produced higher fresh and dry weights of petioles, leaf blades and roots than shallow planting (Table 22), but the differences were not significant. Yield of cormels (kg/pot) with shallow planting were significantly higher than deep planting (Table 22). This might be due to the significantly higher production of suckers with shallow than with deep planting (Table 18).

Outside + 45% Saran Shade: Yield of all components listed in Table 21 were consistently higher for main than for sucker hulis. However, only fresh and dry weights of roots were significantly different. This might be due to the greater production of suckers by main than sucker hulis (Table 17). Results in Table 22 also show generally higher total yields with deep than shallow planting, but the number of cormels and cormel yield (kg/pot) were higher with shallow planting. The significantly greater yield of roots and petioles under deep planting may have been a result of more roots, greater absorption

Table 20. Influence of Planting Depth on Fresh and Dry Weights of Some Characteristics of Taro Grown in Pots, 7 Months after Planting

	Greenhouse + 51% Shade		Outside + 45% Shade		In Full Sun	
	PLANTING DEPTH, CM					
CHARACTER	5	10	5	10	5	10
	FRESH WEIGHTS, g/pot					
Vegetative parts, roots, corms and cormels	1497.1	1485.3	1292.1	1358.9	1189.7	1066.0
	DRY WEIGHTS, g/pot					
Vegetative parts and roots	59.9	68.6	40.9	48.3	38.5	37.8

Table 21. Influence of Type of Huli on Some Traits of Taro Grown in Pots, 7 Months after Planting

TRAIT	Greenhouse + 51% Shade		Outside + 45% Shade		In Full Sun	
	TYPE OF HULI					
	Main	Sucker	Main	Sucker	Main	Sucker
Petiole fresh weight, g/pot	322.75	261.38	158.88	146.75	103.86	99.54
Petiole dry weight, g/pot	24.54	20.30	13.11	11.87	9.28	8.63
Leaf blade fresh wt., g/pot	62.59	61.68	44.11	41.21	30.33	31.13
Leaf blade dry wt., g/pot	7.17	7.28	4.83	4.60	3.53	3.77
Root fresh weight, g/pot	407.63	356.38	418.11a	331.89b	371.79a	269.03b
Root dry weight, g/pot	36.08	33.14	31.64a	23.15b	31.41a	19.64b
Number of cormels/pot	6.0	5.0	6.0	5.0	5.0	5.0
Corm yield, kg/pot	0.55	0.54	0.53	0.53	0.48	0.45
Cormel yield, kg/pot	0.23	0.17	0.25	0.19	0.24	0.19
Total yield, kg/pot	0.78a	0.71b	0.79	0.72	0.71a	0.64b

Means for the same condition and in the same row followed by different letters are significantly different at the 5% level.

Table 22. Influence of Planting Depth on Some Traits of Taro Grown in Pots, 7 Months after Planting

TRAIT	Greenhouse + 51% Shade		Outside + 45% Shade		In Full Sun	
	PLANTING DEPTH, CM					
	5	10	5	10	5	10
Petiole fresh weight, g/pot	275.44	308.68	142.61b	163.03a	89.48b	113.93a
Petiole dry weight, g/pot	20.84	23.99	11.73	13.26	7.71b	10.20a
Leaf blade fresh wt., g/pot	58.40	65.86	40.31	45.01	27.05b	34.40a
Leaf blade dry wt., g/pot	6.70	7.75	4.36	5.07	2.90b	4.40a
Root fresh weight, g/pot	373.25	390.75	359.15	390.84	353.16	287.67
Root dry weight, g/pot	32.38	36.84	24.85b	29.94a	27.86	23.18
Number of cormels/pot	6.0	5.0	6.0	5.0	6.0a	3.0b
Corm yield, kg/pot	0.54	0.56	0.51b	0.55a	0.45	0.48
Cormel yield, kg/pot	0.25a	0.16b	0.24	0.21	0.27a	0.15b
Total yield, kg/pot	0.79	0.72	0.75	0.76	0.72a	0.63b

Means for the same condition and in the same row followed by different letters are significantly different at the 5% level.

of nutrients and manufacture of carbohydrates in the vegetative parts which were translocated into the corms; hence higher corm yield.

Pots in Full Sun: In general, main hulis tended to produce higher yields than sucker hulis (Table 21); however only root fresh and dry weights were significantly different. Main hulis may have produced more and/or longer roots than sucker hulis, which resulted in greater absorption of nutrients; hence greater fresh and dry weights. The greater corm + cormel yield from main hulis might be explained partly by the above reasons and partly by the slightly greater production of petioles and leaf area from the main hulis (Table 17).

Petiole and leaf blade weights were significantly higher with deep than shallow planting (Table 22). Perhaps roots under deep planting were more extensive and/or more efficient in extracting nutrients from the soil. Also, since fewer suckers were produced with deep planting (Table 18), the resulting greater production of leaf blade and petiole weights with deep planting could have occurred at the expense of sucker production. In terms of total production, both cormel and corm + cormel yields were significantly higher under shallow than deep planting (Table 22). This may be due to the significantly greater production of suckers with shallow planting, particularly since the difference between deep and shallow planting for corm yield was not significant. Leaf area was also slightly greater under shallow than deep planting (Table 18), hence another possible explanation for the higher yields under shallow planting.

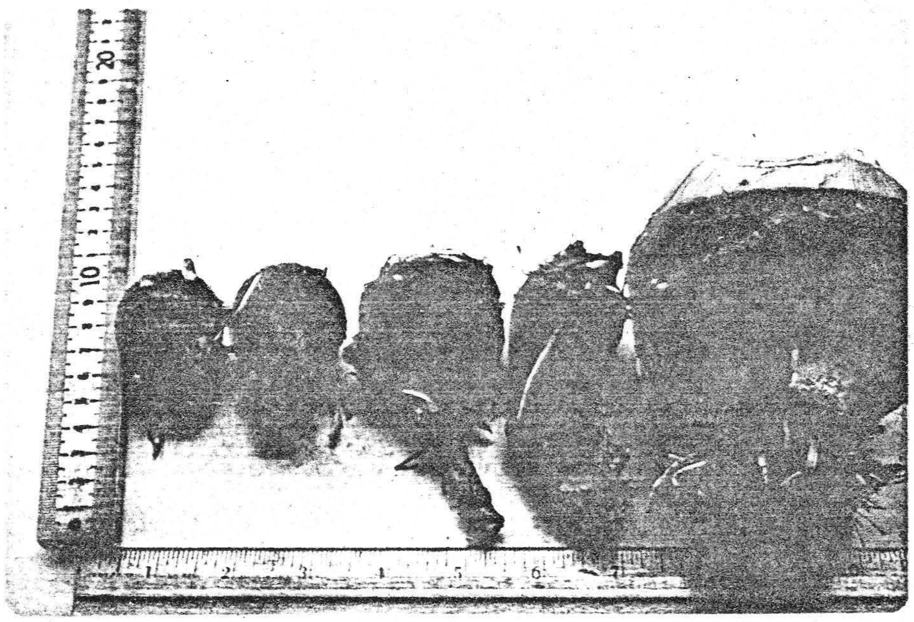
Another interesting feature was the shape of cormels from the two planting depths, particularly those from the greenhouse pots. Cormels from the deep planting tended to bend away more from the corm and had a longer and more slender posterior compared to the 'pear-shape' of those under the shallow planting (Figure 26). A similar observation was made in the field experiment (Figure 10). The shape of the corms was the same under the two planting depths.

Correlation Between Yield and Selected Traits

The correlation coefficients of corm, cormel and total yields on selected traits are shown in Table 23. Total yields for the greenhouse data were not analysed statistically since interest was more in outside pots which were closer to field conditions than the shading experiments.

In general, the relationship between leaves/plant, root fresh weight, root dry weight (except for pots in full sun), leaf area (except for pots in full sun) and yield was rather poor; whereas there was a close association between suckers/plant and yield, particularly for cormels and total yields. This close association is not surprising because of the large contribution of suckers to total yield whereas in the case of petioles and blades, their photosynthates are generally translocated to the corms and cormels. Interestingly, there was also a poor relationship between number of leaves/plant and yield in the field experiment of this study.

The negative association between suckers/plant and corm yield is due to the fact that suckers do not contribute to corm yield but rather as suckers and cormels increase, corm yield decreases; probably as a result of competition. The positive association between corm yield and petiole + blade weights (of mother plant + suckers) but negative association with cormel yield is probably due to the fact that blades and petioles of suckers had not developed to the same extent as those of



a b c

Figure 26. Effect of planting deth on shape of taro cormels (a and b) grown in pots for 7 months. Shape of corms (c) was unaffected at this age. 5 cm depth (a); 10 cm depth (b).

Table 23. Correlation Coefficients of Taro Yield (kg/plant, Grown in Pots for 7 Months) on Selected Traits

TRAIT		CORM			CORMEL			TOTAL YIELD	
	M	G	S	F	G	S	F	S	F[1/]
Planting Depth	7	0.14	0.38*	0.34	-0.41*	-0.18	-0.60**	0.05	-0.45*
Leaves/plant	3	0.09	0.16	0.15	-0.23	-0.12	-0.35*	0.07	-0.27
Leaves/plant	4	0.32	0.43*	0.13	-0.26	-0.22	-0.31	0.05	-0.23
Suckers/plant	3	-0.06	-0.13	-0.43*	0.73**	0.76**	0.84**	0.61**	0.67**
Suckers/plant	4	-0.07	-0.16	-0.37*	0.61**	0.71**	0.82**	0.54**	0.68**
Suckers/plant	5	-0.16	-0.20	-0.36*	0.53**	0.69**	0.85**	0.51**	0.72**
Petiole length,cm	3	0.51**	0.04	0.16	-0.04	0.37*	0.48**	0.36*	0.62**
Petiole length,cm	4	0.46**	0.07	0.47**	-0.10	0.25	0.08	0.22	0.34
Petiole length,cm	5	0.39*	0.19	0.50**	-0.22	-0.10	0.01	0.02	0.29
Petiole dry weight,g	7	0.55**	0.37*	0.72**	-0.30	-0.08	-0.49**	0.14	-0.10
Petiole fresh weight,g	7	0.50**	0.36*	0.75**	-0.32	-0.07	-0.47**	0.14	-0.07
Blade fresh weight,g	7	0.53**	0.53**	0.65**	-0.33	-0.14	-0.56**	0.18	-0.20
Blade dry weight,g	7	0.56**	0.58**	0.65**	-0.39*	-0.23	-0.64**	0.13	-0.30
Root fresh weight,g	7	-0.01	0.11	---	0.18	0.27	---	0.31	---
Root dry weight, g	7	0.12	0.17	-0.28	-0.09	0.10	0.55**	0.19	0.44**
Leaf area dm^2/plant	3	0.41*	-0.13	0.13	0.18	0.03	0.45**	-0.05	0.58**
Leaf area dm^2/plant	4	0.26	-0.08	0.18	0.09	0.15	0.08	0.09	0.23

[1/] M=Months after planting; G=Greenhouse pots + 51% shade; S=Outside + 45% saran shade; F=Full sun;
*, **=5 and 1% significant levels.

the mother-plant and therefore were at a disadvantage in competing for light. Materials for storage in cormels are probably obtained entirely from the vegetative parts of the suckers. This suggestion awaits experimental testing. Thus, through proper techniques such as plant spacing, application of growth regulators and maybe removal of some leaves from the mother-plant, we may be able to manipulate yield towards increased cormels or larger corms.

SUMMARY AND CONCLUSIONS

A 3 x 3 x 2 split-split plot experimental design was conducted in the Hawaiian Islands near the base of the Wailua Valley, Kauai, from June 1974 to June 1975 to evaluate the effect of 3 land preparation methods (flat culture, ridges 13 and 26 cm high), 3 plant populations (25,000, 33,333 and 50,000 plants/ha) and 2 planting depths (8 and 14 cm) on growth of taro in relation to mechanization, with particular reference to planting and harvesting.

A water regime experiment was also conducted in the same location to obtain further information on the effect of water on ease of taro hand harvesting, corm and cormel yields and quality with respect to fermentation, color and flavor.

Pot studies were designed to evaluate the influence of climatic regime, planting depth and type of huli on performance of taro.

Main Field Experiment

Ridge culture produced significantly more suckers per plant than conventional flat culture at three months after planting only. The effect of spacing on sucker production was significant at three, five, seven and nine months after planting, whereas depth of planting had no significant effect on sucker production.

With regards to amount of solids in corms and cormels (g/100g) at 12 months, ridge culture was significantly greater than flat culture. The amount of solids also increased with crop age.

Specific gravity was slightly higher for cormels than for corms in all treatments.

There was no significant difference among treatments for vertical growth of corms, whereas in relation to corm and cormel lateral growth, deep planting had significantly greater growth than shallow planting. This is because cormels tended to bend away more from the corm under the deep than shallow planting. Deep planting would therefore require a broader blade (auger) than shallow planting for mechanical harvesting.

There were no significant differences among all treatments in vertical force required to pull a taro hill. However, the required force was in the order: Flat culture < 26 cm ridge height culture; 20 cm < 40 cm spacing and 8 cm < 14 cm planting depth. Although these results may not be quite conclusive since only 2 plants were sampled per sub-subplot (because of the difficulty involved in making these measurements), they nevertheless demonstrate the fact that taro harvesting requires a lot of energy. This justifies, among other things, the continual interest among farmers in the mechanizing of taro production, particularly planting and harvesting.

Since most farmers usually harvest their taro crop at 12 months or over, conclusions for yields would be based only on the 12 month harvest results.

There was no significant difference in yield due to method of land preparation. Corm, marketable cormels and total yields (metric ton/ha) were as follows: 13 cm ridge height (19.27, 40.18, 62.40); 26 cm ridge height (17.91, 40.11, 60.53) and flat culture (16.92, 35.69, 55.44) respectively. Although yields under ridge culture were not significantly different from those of conventional flat culture, harvesting was easier under the former culture. Furthermore, should a mechanical harvester be developed which requires draining of water, it would be both easier and quicker to drain water with ridge culture. Also, ridge culture would require less water because of the presence of furrows; while moving water plus crop canopy would control weeds, particularly since exposed surface area would be less under this culture than flat culture.

The effect of plant spacing or plant population on corm and cormel yields was significant. Corm, marketable cormels and total tuber yields were: 23.00, 43.10 and 66.00 (50,000 plants/ha); 17.50, 38.30 and 55.80 (33,333 plants/ha); 13.70, 34.50 and 49.40 (25,000 plants/ha) metric ton/ha respectively. Maximum spacing was not ascertained in this study since highest yields were obtained under the closest plant spacing.

Planting depth had no significant effect on yield although deep planting tended to increase yields more than shallow planting. Deep planting is not recommended for adoption in the commercial production of taro because of the undesirable shape of the resulting corms and cormels, particularly cormels, and the fact that if small hulis are planted there would be a greater risk of mortality.

None of the interactions were significant except for spacing x planting depth.

WATER REGIME EXPERIMENT

0 = Continuous flooding

2 = Water drained 2 months before harvest

4 = Water drained 4 months before harvest

Total corms, marketable cormels and total yields (metric ton/ha) at 12 months were: 0 = 36.13, 42.94, 79.98; 2 = 25.40, 49.14, 75.45 and treatment 4 = 18.14, 38.26, 57.31 respectively. Statistical analysis was not done on these data because of poor replication and the fact that corms and cormels were all combined for each treatment.

Man-hours/ha required to pull out taro from the three treatments was as follows: 0 = 305.6, 2 = 844.4 and 4 = 300.0; whereas for the removal of roots, man-hours/ha required were: 0 = 938.9, 2 = 1372.2 and 4 = 961.1. These results further help to demonstrate the fact that labor requirements in the production of taro are quite high and would seem to justify the increased interest among farmers in mechanization with particular reference to harvesting.

The differences in poi fermentation rates, as measured on the basis of pH changes, were minor. However, poi made from treatment 0 appeared to have a slightly faster fermentation rate. Also, the poi that was made from treatment 2 had a pinkish or reddish color compared to the somewhat grayish color of poi made from treatments 0 and 4. Although the differences in flavor and color among the three treatments were not significant, the results suggested a general preference for poi made from treatment 0.

POT STUDIES

1. Greenhouse + 51% shade
2. Outside + 45% saran shade
3. Full sun
    a. Planting depth - 5 and 10 cm
    b. Type of huli - main and sucker

There was a general rapid vegetative growth from time of planting to about 3 - 4 months and then a decline. Also, leaf blades tended to accumulate more dry matter than petioles, probably due to the hollow nature of the petioles. The hollow nature of petioles may be related to an ability to translocate oxygen down to the roots. This has, in fact, been demonstrated in rice using isotopes.

Corm and total yields (corm + cormels) for plants grown in the greenhouse + 51% shade and outside + 45% shade were significantly higher than those grown in full sun. This may be unexpected since radiant energy affects carbohydrate production. Perhaps this was because the strong winds in the experimental site damaged some of the leaves of plants grown in full sun. Also, the greater vegetative growth of the shaded plants could have resulted in a greater translocation of photosynthates for development of corms and cormels, hence higher yields than plants in full sun. The fact that both cormel and total yields under saran shaded treatments were slightly higher than those under greenhouse, but that greenhouse pots consistently out-yielded saran shaded pots for vegetative and root production seems to suggest that vegetative and root growth in the greenhouse occurred at the expense of corms and cormels.

Within a given level of shade, corm and cormel yields of main and sucker hulis in the greenhouse + 51% shade and outside + 45% shade were not significant. However, total yields for main hulis were significantly different from those of sucker hulis in full sun. Also, cormel yield was significantly higher under shallow than deep planting for pots in the greenhouse; whereas for pots outside +45% shade, corm yield under deep planting was significantly higher than shallow planting. With pots in full sun, total cormels and total yields were significantly higher under shallow than deep planting.

An interesting observation made in both field and pot studies was that cormels under deep planting tended to bend away more from the corm. The slender, less compact and hook-like nature of the posterior of cormels under deep planting may not be a desirable consumer characteristic if cormels are to be sold fresh in the market.

APPENDIX

Table 24. Mean Monthly Temperature and Total Rainfall of the Experimental Site during the Crop Period

M O N T H	T E M P E R A T U R E C Maximum	Minimum	TOTAL RAINFALL CM
		1974	
June	26.3	18.8	7.13
July	26.5	20.4	9.44
August	27.6	21.3	6.19
September	28.0	20.3	17.32
October	27.8	20.8	10.41
November	26.1	19.0	18.77
December	25.4	19.8	5.13
		1975	
January	24.1	18.0	28.80
February	24.5	17.1	19.48
March	23.8	17.8	13.13
April	24.8	19.4	3.47
May	25.5	19.4	2.08

Table 25. Analysis of Variance of Taro, Variety Lehua, Leaves and Suckers Per Plant
(M E A N S Q U A R E S)

		Number of leaves/plant				Number of suckers/plant			
		MONTHS AFTER PLANTING							
Source of Variation	d.f.	3	5	7	9	3	5	7	9
Main Plots									
Replicates (R)	2	2.51*	0.145	0.102	0.047	9.33*	5.60	8.78	17.470
Land Preparation (LP)	2	0.16	0.249	0.004	0.260*	11.95*	3.29	8.16	10.186
Error a	4	0.16	0.052	0.040	0.024	0.87	4.60	5.41	8.842
Sub - Plots									
Spacing (S)	2	0.92**	0.330*	0.105	0.051	6.84*	83.30**	180.74**	202.514**
LP X S	4	0.05	0.088	0.036	0.007	0.46	0.38	1.56	1.705
Error b	12	0.09	0.065	0.065	0.040	0.32	1.59	2.36	1.290
Sub - Subplots									
Depth (D)	1	0.14	0.099	0.130*	0.003	0.90	0.04	0.51	5.103
LP X D	2	0.04	0.017	0.037	0.005	0.10	0.30	0.01	0.872
S X D	2	0.08	0.012	0.016	0.037	0.24	0.16	4.50*	4.004
LP X S X D	4	0.03	0.018	0.013	0.011	0.45	0.67	0.61	1.022
Error c	18	0.08	0.029	0.015	0.027	0.26	0.45	1.18	1.234
Total	53								

Table 26. Analysis of Variance of some Taro, Variety Lehua, Traits

Source of Variation	d.f.	Tuber D.W. %	Rotten corms %	Corm vertical growth cm	Corm + cormel lateral growth cm	Circumference per hill cm	Corm specific	Cormel gravity	Corm + cormel D.W. %
		MONTHS AFTER PLANTING							
		10	10	10	10	10	10	10	12
Main Plots									
Replicates (R)	2	83.29*	782.89	3.73	83.68	497.77	0.0106*	0.0061	0.85
Land Preparation (LP)	2	26.45	969.56	4.94	2.24	162.18	0.0012	0.0030	24.85*
Error a	4	4.95	163.44	7.54	9.82	95.53	0.0007	0.0020	2.49
Sub - Plots									
Spacing (S)	2	0.71	1098.50	0.002	17.71	1940.83**	0.0001	0.0016	1.61
LP X S	4	10.71	660.72	0.76	7.92	3.91	0.0011	0.0031	0.51
Error b	12	4.45	654.70	2.76	15.79	27.49	0.0013	0.0012	2.37
Sub - Subplots									
Depth (D)	1	0.15	1120.67*	3.23	26.53*	2.64	0.0002	0.0028	0.50
LP X D	2	0.69	480.67	1.05	8.14	17.35	0.0004	0.0001	0.003
S X D	2	2.78	44.06	0.39	8.70	41.70	0.0016	0.0051*	12.77
LP X S X D	4	1.96	310.72	0.64	7.49	29.43	0.0001	0.0006	2.06
Error c	18	4.32	254.22	1.63	5.64	21.87	0.0007	0.001	3.99
Total	53								

Table 27. Analysis of Variance for 10 Month Taro Cormel Yield (M E A N S Q U A R E S)

Source of Variation	d.f.	Cormels Ton/ha	Cormels Kg/plant
Main Plots			
Replicates (R)	2	318.93	0.222
Land Preparation (LP)	2	115.17	0.078
Error a	4	142.26	0.105
Sub - Plots			
Spacing (S)	2	51.36	1.036**
LP X S	4	6.49	0.004
Error b	12	22.42	0.018
Sub - Subplots			
Depth (D)	1	5.24	0.002
LP X D	2	27.64	0.014
S X D	2	1.20	0.001
LP X S X D	4	33.99	0.028
Error c	18	17.29	0.011
Total	53		

Table 28. Analysis of Variance of 12 Month Taro, Variety Lehua, Yields
(M E A N S Q U A R E S)

Source of Variation	d.f.	Corm	Marketable cormel	Total cormel	Corm + Marketable cormel	Total yield
		T O N S P E R H E C T A R E				
Main Plots						
Replicates (R)	2	112.47*	1065.30**	718.77**	1804.44**	1347.62**
Land Preparation (LP)	2	30.88	144.84	135.88	287.41	280.56
Error a	4	14.31	28.70	30.34	46.98	42.21
Sub - Plots						
Spacing (S)	2	474.83**	411.47**	528.51**	1768.66**	2001.32**
LP X S	4	25.89	50.78	57.30	97.22	108.64
Error b	12	21.65	48.61	65.44	86.77	109.08
Sub - Subplots						
Depth (D)	1	2.00	124.03	62.99	93.19	41.29
LP X D	2	14.20	15.42	5.02	1.73	9.01
S X D	2	21.70	301.48**	319.21**	337.14*	357.82*
LP X S X D	4	8.02	34.96	34.51	54.64	52.67
Error c	18	8.35	46.50	49.62	60.65	63.79
Total	53					

Table 29. Analysis of Variance of Taro Yield at 12 Months
(M E A N S Q U A R E S)

Source of Variation	d.f.	Corm Kg/plant	Marketable cormel Kg/plant	Number of marketable cormels/ha
Main Plots				
Replicates (R)	2	0.078*	1.135**	1942768791
Land Preparation (LP)	2	0.028	0.159	1520498050
Error a	4	0.007	0.052	7515159717
Sub - Plots				
Spacing (S)	2	0.038	1.473**	53828096388**
LP X S	4	0.029	0.075	2443307425
Error b	12	0.010	0.108	2451934339
Sub - Subplots				
Depth (D)	1	0.00001	0.045	10837301667
LP X D	2	0.006	0.005	10124353472
S X D	2	0.009	0.278**	14826204167*
LP X S X D	4	0.003	0.030	5542772430
Error c	18	0.004	0.032	2956641543
Total	53			

Table 30. Insignificant Interaction of Land Preparation Method X Planting Depth on Taro Yields (metric ton/ha) at 10 and 12 Months

	LAND PREPARATION METHOD					
	Flat Culture		Ridges 13 cm High		Ridges 26 cm High	
	PLANTING DEPTH, CM					
YIELD COMPONENT	8	14	8	14	8	14
			10 MONTHS			
Corms	13.61	14.06	18.63	16.35	18.74	16.33
Total Cormels	27.52	27.86	32.26	29.13	25.66	26.74
Total Yield	41.13	41.92	50.89	45.48	44.40	43.07
			12 MONTHS			
Corms	17.99	15.84	19.25	19.36	17.44	18.37
Total Cormels	37.10	39.94	42.57	43.50	41.56	43.67
Total Yield	55.09	55.78	61.82	62.86	59.00	62.04

Corms and total yields were not analysed statistically because of rotten corms in some plots at 10 months.

Table 31. Insignificant Interaction of Land Preparation Method X Planting Depth on Taro Yields (Kg/plant) at 10 and 12 Months

	LAND PREPARATION METHOD					
	Flat Culture		Ridges 13 cm High		Ridges 26 cm High	
	PLANTING DEPTH, CM					
YIELD COMPONENT	8	14	8	14	8	14
			10 MONTHS			
Corms	0.38	0.39	0.52	0.45	0.52	0.45
Total Cormels	0.81	0.83	0.95	0.87	0.77	0.79
Total Yields	1.19	1.22	1.47	1.32	1.29	1.24
			12 MONTHS			
Corms	0.49	0.45	0.54	0.55	0.49	0.53
Marketable cormels	1.00	1.10	1.21	1.25	1.14	1.18
Corms + marketable cormels	1.49	1.55	1.75	1.80	1.63	1.71

Corms and total yields at 10 months were not analysed statistically because of rotten corms in some plots.

Table 32. Insignificant Interactions between Plant Spacing and Planting Depth on Taro Yields at 10 Months[1/]

	SPACING, CM					
	100 x 20		100 x 30		100 x 40	
	PLANTING DEPTH, CM					
YIELD	8	14	8	14	8	14
	TON/HA					
Corms	21.48	16.28	12.37	14.82	13.57	15.13
Total cormels	29.50	28.57	29.13	28.99	26.68	26.18
Total Yield	50.98	44.85	41.50	43.81	40.25	41.31
	KG/PLANT					
Corms	0.43	0.33	0.37	0.45	0.55	0.61
Total cormels	0.59	0.57	0.88	0.87	1.07	1.05
Total Yield	1.02	0.90	1.25	1.32	1.62	1.66

[1/] Corms and total yields were not analysed statistically due to rotten corms in some plots.

Table 33. Insignificant Effect of Land Preparation Method X Plant Spacing X Planting Depth on Taro Yields (metric ton/ha) at 10 Months*

Plant Population	LAND PREPARATION METHOD: Flat Culture		Ridges 13 cm High		Ridges 26 cm High		MEANS	
	PLANTING DEPTH, CM: 8	14	8	14	8	14	8	14
				CORMS				
25,000	12.45	15.13	13.44	17.35	15.34	12.93	13.74	15.14
33,333	9.24	9.90	11.49	16.12	17.51	23.43	12.75	16.48
50,000	19.15	17.16	24.81	15.78	21.88	16.04	21.95	16.33
				CORMELS				
25,000	26.17	26.56	27.65	28.53	26.18	23.45	26.67	26.18
33,333	26.16	28.88	36.33	28.60	24.88	29.47	29.13	28.99
50,000	30.20	28.14	32.81	30.27	25.90	27.29	29.64	28.57
				TOTAL YIELD				
25,000	38.62	41.69	41.09	45.88	41.52	36.38	40.41	41.32
33,333	35.40	38.78	47.82	44.72	42.39	52.90	41.88	45.47
50,000	49.35	45.30	57.62	46.05	47.78	43.33	51.59	44.90

*Corm and total yields were not analysed statistically because of rotten corms in some plots.

Table 34. Insignificant Effect of Land Preparation Method X Plant Population X Planting Depth on Taro Yields (metric ton/ha) at 12 Months

Plant Population	LAND PREPARATION METHOD: Flat Culture		Ridges 13 cm High		Ridges 26 cm High		MEANS	
	PLANTING DEPTH, CM: 8	14	8	14	8	14	8	14
				CORMS				
25,000	11.14	10.00	14.62	15.52	14.49	16.49	13.42	14.01
33,333	17.40	18.97	18.37	18.57	15.00	16.24	16.92	17.93
50,000	25.43	18.54	24.61	24.00	22.82	22.41	24.29	21.65
				MARKETABLE CORMELS				
25,000	34.95	27.66	38.06	36.45	37.49	32.31	36.83	32.14
33,333	28.98	46.04	36.82	41.30	33.00	42.94	33.27	43.43
50,000	35.11	43.18	43.18	45.27	46.97	47.95	41.75	44.53
				TOTAL CORMELS				
25,000	37.92	28.74	40.74	38.17	39.45	34.38	39.37	33.77
33,333	33.92	48.06	40.55	42.52	34.65	45.56	36.37	46.05
50,000	39.48	43.02	46.39	47.81	50.59	51.08	45.49	47.31
				TOTAL YIELD				
25,000	49.06	38.74	55.36	53.69	53.94	50.87	52.79	47.78
33,333	51.32	67.03	58.92	63.09	49.65	61.80	53.39	63.98
50,000	64.91	61.56	71.00	71.81	73.41	73.49	69.78	68.96

Table 35. Analysis of Variance for Vertical Force Required to Pull a Taro Hill
(MEAN SQUARES)

Source of Variation	d.f.	(Kg/hill)
Main Plots		
Replicates (R)	2	180.73
Land Preparation (LP)	1	54.60
Error *a*	2	167.82
Sub - Plots		
Spacing (S)	1	85.13
LP X S	1	64.03
Error *b*	4	53.76
Sub - Subplots		
Depth (D)	1	21.66
LP X D	1	0.03
S X D	1	26.88
LP X S X D	1	4.00
Error *c*	8	18.25
Total	23	

Table 36. Grand Means and Coefficients of Variation (C.V.) of 12 Month Taro Yields (tons/ha

Yield Component	Grand Mean	Land Preparation Method	Plant Spacing	Planting Depth
		COEFFICIENT OF VARIATION (C.V.)		
Corms	19.88	19.02	23.4	14.53
Marketable cormels	42.61	12.57	16.36	16.00
Total cormels	45.64	12.07	17.73	15.44
Corms + marketable cormels	62.50	10.96	14.90	12.46
Corms + total cormels	65.52	9.91	15.94	12.18

Table 37. Influence of Land Preparation Method, Plant Population and Planting Depth on Taro Leaf Area and Mother-Plant Leaf Area Index at 3 Months and Yield at 12 Months

		PLANTING DEPTH, CM					
		8			14		
Land Preparation	Plants/ha	Leaf area dm^2	Leaf area index	Total yield (Ton/ha)	Leaf Area dm^2	Leaf Area index	Total yield (Ton/ha)
Flat Culture	25,000	11.20	1.20	54.08	10.98	1.25	42.71
	33,333	10.91	1.51	56.57	10.90	1.54	73.88
	50,000	11.25	2.28	71.55	11.37	2.29	67.86
Ridges 13 cm high	25,000	14.34	1.58	61.03	15.90	1.84	59.18
	33,333	13.50	1.88	65.19	15.28	2.16	69.55
	50,000	13.91	2.64	78.27	13.50	2.74	79.15
Ridges 26 cm high	25,000	15.46	1.60	59.46	14.17	1.51	56.07
	33,333	14.22	1.93	54.71	14.44	2.10	68.12
	50,000	13.40	2.61	80.92	14.00	2.54	81.00

Table 38. Analysis of Variance for Taro Poi Flavor and Color Used in the Taste Panel

(MEAN SQUARES)

Source of Variation	d.f.	Flavor (Ranking Scale)	Color (Ranking Scale)
Replicates (Tasters)	8	2.39	3.04
Treatments	2	0.85	0.45
Error	16	1.99	1.26
Total	26		

Table 39. Analysis of Variance of 7 Month Taro Yields Grown in Pots in Full Sun

Source of Variation	d.f.	Corms (KG/POT)	Cormels (KG/POT)	Corms + Cormels (KG/POT)	Total Cormels (NUMBER/POT)	Marketable Cormels (NUMBER/POT)
		(M E A N	S Q U A R E S)			
Replicates	7	0.004	0.008	0.011	3.353	1.339
Type of huli (H)	1	0.006	0.020	0.041**	0.781	3.125
Planting depth (D)	1	0.012	0.112**	0.059**	47.531**	15.125**
H X D	1	0.001	0.002	0.004	1.531	0.125
Error	21	0.003	0.006	0.005	2.948	1.435
Total	31					
Grand Means		0.465	0.211	0.673	4.656	3.063

Table 40. Analysis of Variance of 7 Month Taro Yields Grown in Pots

Source of Variation	d.f.	SARAN + 45% SHADE			IN GREENHOUSE 51% SHADE		
		Corms	Cormels	Corms + Cormels	Corms	Cormels	Corms + Cormels
		KG PER POT (MEAN SQUARES)					
Replicates	7	0.0013	0.005	0.004	0.0107	0.008	0.018
Type of huli (H)	1	0.0003	0.029	0.036	0.0003	0.028	0.048*
Planting depth (D)	1	0.015 *	0.008	0.0009	0.0041	0.057*	0.020
H X D	1	0.0004	0.0002	0.001	0.0011	0.004	0.004
Error	21	0.003	0.008	0.011	0.006	0.009	0.006
Total	31						
Grand Means		0.531	0.225	0.756	0.547	0.203	0.757

Combined Analysis

		Number of cormels per pot	Corms	Cormels	Corms + Cormels
			KG PER POT		
Location	2	3.764	0.064**	0.010	0.089**
Reps. in location (error)	21	4.443	0.0052	0.004	0.011

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